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REVIEW OF RESEARCH RELATED TO  
SULFATES IN THE ATMOSPHERE

REPORT

PREPARED FOR THE  
SUBCOMMITTEE ON THE ENVIRONMENT  
AND THE ATMOSPHERE

OF THE

COMMITTEE ON  
SCIENCE AND TECHNOLOGY  
U.S. HOUSE OF REPRESENTATIVES  
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## LETTER OF TRANSMITTAL

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APRIL 2, 1976.

HON. OLIN E. TEAGUE,  
*Chairman, Committee on Science and Technology,*  
*U.S. House of Representatives, Washington, D.C.*

DEAR MR. CHAIRMAN: I am transmitting herewith a report entitled "Review of Research Related to Sulfates in the Atmosphere." The report is based on hearings on the subject held before our Subcommittee in July of 1975 and a thorough analysis of the pertinent literature. The report is particularly timely and contains much information which I believe will be very useful to the Members as they consider legislation now before the Congress.

I am happy to acknowledge that Dr. Gordon Dunn is primarily responsible for the staff work involved in preparing this report.

Mr. Chairman, I commend this report to you and the other Members.

Sincerely,

GEORGE E. BROWN, JR.  
*Chairman, Subcommittee on the*  
*Environment and the Atmosphere.*

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# CONTENTS

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	Page
Letter of Transmittal.....	III
I. Introduction.....	1
II. What Is Known?.....	5
Stationary Sources: Formation and Transport.....	5
Stationary Sources: Control.....	8
Mobile Sources.....	12
Health Effects.....	13
Other Effects.....	16
Measurements of Sulfate Concentrations.....	17
III. Information Needed.....	19
IV. Discussion and Findings.....	21
V. Action.....	27
Appendix A: Summary from "Air Quality and Stationary Source Emission Control".....	31
Appendix B: Executive Summary from "Position Paper on Regulation of Atmospheric Sulfates".....	43
Appendix C: Model Research Institute.....	55
Appendix D: Workshop on Health Effects of Fossil Fuel Combustion Products.....	59
References and Notes.....	61





## I. INTRODUCTION

Growing evidence shows that the increasing atmospheric burden of anthropogenic sulfur dioxide and its transformation products (these products are generically here referred to as sulfates (1)) gives rise to a health and welfare insult to man and his environment which should not be tolerated. Thus, preliminary data indicate that concentrations of the order of 10 micrograms of sulfates per cubic meter of air may present a health hazard to certain population groups, and some 24 states in the northeastern USA already exhibit annual average concentrations surpassing this.

The problem of sulfates in the atmosphere comes largely from activity and projected growth associated with energy production. There appears to be a conflict between the maintenance of air quality and the fulfillment of national energy requirements. Combustion of fossil fuels generates sulfur dioxide and other pollutants. The sulfur dioxide eventually converts in large part to sulfates in the atmosphere. Under the Clean Air Act primary and secondary standards have been established for ambient sulfur dioxide concentrations, and new source performance standards have been set for sulfur dioxide emissions from combustion facilities. However, ambient and new source standards have not been set for sulfates, even though the evidence available indicates that sulfates are more damaging to health at a given concentration than is sulfur dioxide. Most experts agree that the reason for this seeming inconsistency is that there is inadequate knowledge of sulfate formation and transport and of the health and welfare effects of specific sulfates to promulgate standards under the Clean Air Act.

Having enough knowledge to recognize the health problem that the sulfates present, but inadequate knowledge to promulgate standards places decision makers in a difficult position. For example, energy demands continue to increase, and it is clear that a larger fraction of energy is going to come from coal. Coal generally has higher sulfur content than the low sulfur oil on which we have relied for a number of years now, but which becomes increasingly scarce. Estimates are that the sulfur oxides load to the atmosphere would double by 1990 in the absence of controls. Industry wants to invest its scarce capital in a manner which will allow them to meet clean air regulations in the least expensive way. Thus, they have been asking for relaxation of new source standards to allow the sulfur oxides from remote power plants to be emitted from very tall stacks (up to 1200-1300 feet). They point out that ambient sulfur dioxide standards can be met with this approach. However, the emission of sulfur dioxide at such heights allows more of it to be converted to sulfates, and since sulfates have a longer residence time in the atmosphere, the total sulfur oxide burden of the atmosphere is increased and it is in a form indicated to be more damaging to health. But there are no standards for sulfates. The lack of knowledge thus leaves industry unable to

decide how best to invest its pollution control dollars, and this can in turn lead to delays in construction of needed energy facilities. It leaves the Administration and Congress with incomplete parts of the picture they must view in making long range energy and environmental policies. It leaves the Environmental Protection Agency in a quandry as to how best to protect public health and welfare.

Most important of all, it leaves the public exposed to levels of sulfate concentrations damaging to their health, not to mention other adverse effects of this pollution on public welfare. On the latter, sulfates have been linked to acid rain and its incompletely investigated consequences which probably include damage to crops, to fisheries, to plant and animal life, to buildings, and to statuary. Also, sulfates are frequently a major cause of visibility degradation.

Another recently emerging issue which is complicated by the lack of knowledge of sulfates, is that involving the sulfuric acid emitted by autos with catalytic converters for pollution control. Some catalytic converter configurations lead to emission of a fine sulfuric acid aerosol. Many experts feel that all three of the regulated pollutants ( $\text{HC}$ ,  $\text{CO}$ ,  $\text{NO}_x$ ) cannot be controlled to the mandated levels without having dangerous amounts of this accompanying acid aerosol or without implementing entirely new or incompletely developed technology. (This will be discussed further below.) When this problem was belatedly recognized, the research community found itself without adequate techniques to measure roadside concentrations of sulfuric acid—so that one could only estimate with rather uncertain computational procedures what the acid concentrations would be. Furthermore, knowledge of the health effects of sulfuric acid aerosol is inadequate to unequivocally decide whether there is more potential damage from the acid or from the hydrocarbon and carbon monoxide if these latter aren't controlled to the full level mandated. Again, large investments, long range decisions, and public health have been put into a netherland defined by inadequate sulfates knowledge. The Environmental Protection Agency estimates that a minimum of 5 years will be needed to obtain the knowledge level needed to promulgate standards for sulfates.

The Committee on Science and Technology, Subcommittee on the Environment and the Atmosphere has responsibility for legislation relating to environmental research and development programs including, but not limited to, EPA's research and development programs in Air and Water Quality and Solid Waste Disposal. The investment of billions of dollars, the health and welfare of the American public, and decisions affecting the route and rate for achieving energy independence of the Nation hinge on our knowledge of the sulfates issue. Decision analysis (2) on the subject has indicated that accurate knowledge of the issues involved with the sulfates problem is worth approximately \$250,000,000 per year. The 94th Congress has been considering amendments to the Clean Air Act which would allow relaxation of new source performance standards for stationary sources and which would allow relaxation and postponement of automobile emissions standards. Both of these issues are being considered with inadequate information. It is the responsibility of the Subcommittee to insure to the best of its ability that adequate research is being conducted to provide the needed information in as timely a way as



possible. To meet this responsibility the Subcommittee conducted hearings (3, 4) July 8, 9, 11, and 14, 1975, to clarify what is known about the sulfates, what is not known but needs to be, what reasons there are for our lack of knowledge, what is being done to remedy the situation, and what, if any, changes in the research program could be implemented to optimize chances of success.

Testimony was received from the following witnesses:

#### JULY 8, 1975

Prof. Joe W. Hightower, Department of Chemical Engineering, Rice University.

Eric O. Stork, Deputy Assistant Administrator for Mobile Source Air Pollution Control, Environmental Protection Agency; accompanied by John Knelson, M.D., Acting Director, Health Effects Research Laboratory, Office of Research and Development, Research Triangle Park, N.C.; John Moran, Director, research catalyst program, Office of Research and Development, Research Triangle Park, N.C.; Dr. Robert Papetti, Acting Director, Air Quality Staff, Office of Air, Land and Water, Office of Research and Development, Environmental Protection Agency; Joseph J. Merenda, Assistant to the Deputy Assistant Administrator, Mobile Source Air Pollution Control, Office of Air and Waste Management.

Dr. Stephen G. Miller, director, Avram Co.

Herbert L. Misch, vice president, environmental and safety engineering staff, Ford Motor Co.; accompanied by Dr. Serge Gratch, director, chemical sciences laboratory, Ford Motor Co.

Ernest S. Starkman, vice president, environmental activities staff, General Motors Corp.; accompanied by Charles Tuesday, technical director, General Motors research laboratory.

Dr. D. Maxwell Teague, chief research scientist, Chrysler Corp.

#### JULY 9, 1975

Dr. George Hidy, general manager, Western Technical Center, Environmental Research and Technology.

Dr. Carl Shy, University of North Carolina.

Prof. Ellis Cowling, North Carolina State University.

#### JULY 11, 1975

Carl G. Beard II, director, West Virginia Air Pollution Control Commission.

Howard E. Hesketh, Ph. D., P.E., professor of engineering, Southern Illinois University.

Donald G. Allen, vice president, New England Electric System; accompanied by George C. Freeman, Jr., Coordinating Committee's Special Counsel.

Dr. Stanley Greenfield, president, Greenfield, Attaway & Tyler, Inc.

#### JULY 14, 1975

John Hill, Deputy Administrator, Federal Energy Administration.

Dr. John Finklea, Director, NIOSH.

Dr. Wilson K. Talley, Assistant Administrator for Research and Development, Environmental Protection Agency.

The hearings proved valuable not only in presenting summaries of various aspects of the complex sulfate issue, but also in highlighting the concerns and interests of the parties involved in the issue. They served to emphasize the high stakes and keen interest that industry, government, and the public all have in research on sulfates.

A primary finding of the Subcommittee is that there is not a coordinated, targeted research program on the sulfates, even within the EPA. This is probably due in large measure to the apparent belief on the part of regulatory officials that a regulation of sulfur dioxide implies a *de facto* regulation of sulfates. Evidence now shows this may not be so. The sulfates issue is broad enough and of such consequence that the EPA, coordinating with ERDA, HEW, and NSF, should develop and implement such a program without further delay.

The Subcommittee found a number of specific areas in the EPA research program deserving attention in a variety of contexts. Many of these involve practices or facilities that go beyond the sulfates issue, but have been highlighted by the sulfates investigation. For example, it was found that advance in knowledge in the critical areas of formation and transport of sulfates and of the health effects of sulfate depends in a key way upon development and implementation of adequate measurement technology. The measurement program and other items deserve attention, and these will be discussed later.

Section II gives a brief discussion of the sulfate problem, including an outline of how sulfates are formed, what the main health and welfare effects are, and the status of control technology for sulfates. Section III lists the things not known about sulfates and the consequences of this. Section IV is a discussion of some of the issues involved in optimizing the effort of providing knowledge on the sulfates issue, and makes a number of suggestions pertaining to the research program. Section V lists a number of action items suggested to improve the rate of progress toward understanding of sulfates.

It should perhaps be mentioned here that the focus on sulfates in this report does not imply that other air pollutants are not as important. In particular, nitrogen oxides, small particles, and other products of combustion also deserve special attention since many of the anticipated problems are associated with increasing energy needs, and the obtaining of much of that energy from combustion of fossil fuels.

## II. WHAT IS KNOWN?

Sulfur oxides in the atmosphere have long been connected with adverse health and welfare effects, and serious studies have been conducted over nearly half a century. (The primary measured variable in most of these studies was sulfur dioxide.) An extensive literature has built up over this period, including a number of reviews. In particular, the recent concern about sulfates has led to a good overview in the form of a report (2) by the National Academy of Sciences which covers essentially all aspects of the problem. The health effects issue has been critiqued in a report, (5) prepared for the Edison Electric Institute and the Electric Utility Industry Clean Air Coordinating Committee and in a report (6) prepared for the Federal Energy Administration. Many of the issues have been discussed in a report (7) prepared for the Manufacturers of Emission Controls Association on the automobile sulfates issue. The Congressional Research Service has prepared a committee print (8) on the problem, and this has been issued by the Subcommittee on the Environment and the Atmosphere. The Subcommittee hearing record (3) includes References 4 and 5, and the testimonies of witnesses provide good views of the various parts of the issue. The Environmental Protection Agency has issued a position paper (9) which discusses most aspects of the sulfates issue, though in much less depth than the National Academy of Sciences report. (2) The citations given here contain further references to the primary scientific literature.

In this section, facts concerning our knowledge of formation and transport, health and welfare effects, and control of sulfates are briefly laid out. This is supplemented by the summary of Parts 1 and 2 of the National Academy of Sciences report (2) included as Appendix A, and by the executive summary of EPA's position paper (9) included as Appendix B.

### *Stationary Sources: Formation and Transport*

Compounds of sulfur enter the atmosphere of the globe from many sources dominated by natural ones: biological processes contribute hydrogen sulfide ( $\text{H}_2\text{S}$ ) which accounts for about 49 percent of the total equivalent sulfate burden, wind blown sea spray contributes sulfate salts directly and accounts for about 23 percent, and volcanoes contribute hydrogen sulfide, sulfur dioxide, and sulfate salts and account for about 1 percent of the sulfate burden. The remaining 27 percent is put into the atmosphere by man's activities, mostly in the form of sulfur dioxide ( $\text{SO}_2$ )—from stationary fuel combustion (21 percent), industrial processes (5 percent), and transportation (1 percent). In tons, man puts about 150,000,000 tons of equivalent sulfate into the atmosphere each year. Much of the hydrogen sulfide and sulfur dioxide is converted by various chemical processes to higher oxides, generically here referred to as sulfates, which take the form of aerosols. The main mechanisms by which the atmosphere becomes



cleansed of sulfur compounds include dry deposition, rainout, and plant uptake.

Though man's input of sulfur to the atmosphere is "only" about one-fourth of the total, his activities are relatively localized, and sulfur dioxide and sulfate concentrations are much higher near areas of high human activity. In other words, in industrialized regions man's activities overwhelm natural processes, and the removal processes are slow enough that the increased concentration is marked for hundreds of kilometers downwind. The impact is put into some focus by noting that in non-urban sites in non-industrialized parts of the U.S. annual average sulfate concentrations range around 1-3 micrograms of sulfate per cubic meter of air. In urban sites in industrialized parts of the country, annual average concentrations range around 12-24 micrograms per cubic meter—about 10 times higher! Thus, about 80 to 90 percent or more of the sulfur oxides present in cities is anthropogenic.

National primary and secondary ambient air quality standards for sulfur dioxide are mandated under authority of the Clean Air Act of 1970. These and new source performance standards are shown in the table at the end of Appendix A, p. 40. Individual states have been required to file State Implementation Plans showing how the standards will be met in the states. There are no Federal standards for sulfates. A small number of states and local jurisdictions have standards for sulfuric acid mist and for suspended sulfates.

As a part of "Project Independence," many utilities and other energy intensive industries will convert within the next few years from burning low sulfur imported oil and natural gas to burning coal, which generally contains more sulfur. Both the Administration and the Congress have projected (3, 9) a doubling of the use of coal over the next 10 years. It is projected that without emission controls, sulfur oxides emissions will double by 1990. With enforcement of State Implementation Plans for emission control and of New Source Performance Standards, the sulfur oxides emissions in 1990 are projected (9) to be approximately what they were in 1975. As was mentioned in the introduction and as will be discussed in more detail later, the 1975 sulfate levels already are such that preliminary data indicate them to be a serious health problem.

Most of the sulfur compounds entering the atmosphere from combustion processes are in the form of sulfur dioxide. Conversion of the sulfur dioxide to sulfates proceeds by a variety of chemical and photochemical reactions with other atmospheric constituents.

If the reaction rates are rapid compared to the time for sulfur dioxide to deposit onto the ground or plants, then one will have sulfate concentrations relatively high compared to when the reaction rates are slow. The reaction rates depend upon variables such as sunlight intensity and spectral character; concentrations of various reactants such as organic oxidants, nitrogen oxides, and ammonia; humidity; and temperature. It will be recognized that some of these are potentially controllable while others are not. Though some specific reactions are understood, little is known about most of the reactions involved and the chains and combinations are poorly understood. The chemistry is severely complicated by mixing and transport in the atmosphere.

Chemical forms of sulfates in urban atmospheres resulting from this complex of chemical transformations are deduced by a series of measurements to be primarily ammonium sulfate, ammonium acid sulfate, and sulfuric acid aerosol. Various organic and metallic sulfates are also thought to be present in smaller concentrations. However, most sulfate measurements to date (as in the National Air Surveillance Network, for example, see Reference 1), do not provide chemical species information, and knowledge is quite incomplete. An important characteristic of sulfate particulates is the size distribution. Particles of less than 1 micron (a millionth of a meter) are readily respirable and ingested into the deep lung. Larger particles are captured in the nose or throat. As it turns out, sulfates derived by transformation of sulfur dioxide generally fall into the small or respirable range. This is in contrast to wind blown sea spray particulates which fall into a size distribution around 10 microns. The small particles deriving from man's activities are potentially more hazardous to health by virtue of their respirability. Furthermore, these small particles have a very long lifetime in the atmosphere before settling out, so that they can travel for hundreds of miles from their source.

Analysts, officials, and other associated with the sulfate issue have most often made the tacit assumption in their work that concentrations of sulfates are proportional to those of sulfur dioxide. Indeed, this view is quite intuitive—that the number of “daughters” be proportional to the number of “parents.” Helping to entrench this view further is the fact that maps (2) showing geographical distribution of industrial activity correlate well with maps showing sulfur dioxide concentrations; and these in turn correlate well with maps showing sulfate concentrations. A good association between these two pollutants may especially be expected in source areas which are relatively isolated from the influence of other major emission sources and which do not have high levels of atmospheric constituents that influence sulfate formation. A good correlation (9) in such an isolated area has indeed been found near a relatively remote smelter in the Salt Lake Valley. Generally, ambient sulfur dioxide and sulfate levels were significantly correlated at the test sites located about 5, 10, 15 and 40 miles from the smelter. The smelter was closed down during a strike in 1971. Average sulfate concentrations, which had ranged between 13 and 6 micrograms per cubic meter, depending upon distance, dropped to about 4 micrograms per cubic meter at all sites during the strike.

However, other data indicate that this pleasantly simple and intuitive relationship does not hold when source conditions are not simple, as for example, in the Los Angeles area or the Northeast U.S. where there are many sources of sulfur dioxide, and also high concentrations of oxidants, nitrogen oxides, and other (2) possible precursors to sulfate formation. Nationally, average concentrations of sulfur dioxide measured in the National Air Surveillance Network showed a general decline of about a factor of 2 between 1964 and 1970. However, sulfate concentrations stayed nearly constant. In specific locations the non-proportionality observed is even more striking: In New York average sulfur dioxide concentrations between the periods 1964–1966 and 1970–1973 were reduced a factor of 9, while sulfate concentrations were reduced by only a factor of 1.5. In Newark, New Jersey the



corresponding factors were 22 and 1.2. In Pittsburgh and Denver sulfates actually increased while sulfur dioxide decreased: In Pittsburgh when sulfur dioxide was cut by a factor of 1.6, sulfates increased by a factor of 1.4. In Denver the comparable figures were 1.9 and 1.6. Before 1965 both sulfur dioxide and sulfate concentrations showed high winter and low summer values, characteristic of sulfur dioxide emissions. After 1965, sulfate levels started showing peaks in the summer—just opposite the sulfur dioxide emissions and concentrations.

A variety of hypotheses have been put forth to explain the observed non-proportionality of the two pollutants. (This non-proportionality is extremely important, since it has rather far reaching consequences in any strategy to control sulfates, as discussed later). One hypothesis points out that new power plants have been built in rural areas, so the sulfur dioxide from these plants doesn't reach the cities, but sulfates, which travel further, do reach the cities. The periods of observation were periods involving more and more use of low sulfur fuels by urban users, so sulfur dioxide levels went down; but the sulfate concentrations were now made up of the decreased values from urban sources plus the concentrations of sulfates "imported" from the new rural plants, with a net effect of staying roughly constant. Another hypothesis which may explain some of the observations puts the burden on the complex chemistry involved in conversion of sulfur dioxide to sulfates. If the limiting factor in the rate of sulfate formation is the concentration of a precursor (e.g., oxidant or nitrogen oxide), then one would not expect to see any significant change of sulfate concentrations if only sulfur dioxide concentrations are changed. In this case, one would have to change the precursor concentration, or decrease the sulfur dioxide concentration until it did become the limiting factor in the formation rate in order to affect the sulfate concentration. The hypotheses above are the ones generally considered. Another hypothesis put forth departs considerably from conventional thinking on the subject and attributes the sulfates primarily to conversion of hydrogen sulfide rather than sulfur dioxide. As noted above, hydrogen sulfide is a product of bacterial decay of organic matter. The hypothesis is that hydrogen sulfide levels are markedly increased in industrial areas where water pollution is high, due to anaerobic bacterial action in the polluted waters. There are not enough data to determine which (if any) of the hypothetical mechanisms dominates in a given area.

#### *Stationary Sources: Control*

From the above discussion, it is clear that control of sulfates may involve completely different approaches in different areas. The conventional view has been that by control of sulfur dioxide, one has a *de facto* control of sulfates. If true proportionality exists, as was found in the Salt Lake Valley, or if the transport hypothesis is the only reason for observed non-proportionalities, then indeed control of sulfur dioxide should lead to control of sulfates. On the other hand, it is quite possible that in heavily polluted areas, sulfate levels are limited by concentrations of various precursors as in the second hypothesis above. Until the reactions are understood, one cannot say what control action would be optimum, but it probably would involve control of the precursors involved, or some combination of sulfur dioxide and the precursors. If the third hypothesis should

prove valid, and this mechanism is dominant, then we are put into the amusing but serious situation of cleaning our waters to clean our air (not unlike the old outdoorsman's admonition: If your feet are cold, put on your hat).

Since there are mandated standards for sulfur dioxide, a great deal of research and development have gone into the problem of sulfur dioxide control. As it has long been tacitly assumed that this would also lead to sulfate control (and it may yet prove to be the case), it is useful here briefly to summarize control possibilities for sulfur dioxide. Table 1 (9) lists various control techniques, their sulfur removal efficiency (with 3% coal as a base) and other relevant factors to be included in assessing the methods. A recent report (10) prepared for the Department of Commerce by the Commerce Technical Advisory Board concluded that a combination of physical coal cleaning and stack gas scrubbing was the optimum strategy in terms of overall cost, meeting air quality standards, and minimizing the solid waste problem normally attendant to the scrubbing technique. The utilities industry has issued a report (11) which recommends policies which will assure that primary and secondary air quality standards for sulfur dioxide are met, but which will relax new source performance standards. Basically, this would mean using tall stacks in rural areas with no real sulfur oxides removal or limitation. As has already been mentioned, this puts the sulfur dioxide at a high enough altitude that it can be expected to remain in the atmosphere longer, so that more of it could be expected to be converted to sulfate. Since sulfates have a longer residence in the atmosphere, the total sulfur oxide burden might be both increased and converted to a form more damaging to health and welfare. This option, as an interim allowed procedure until research better clarifies the sulfates issue is being considered in the 94th Congress under proposed amendments to the Clean Air Act. This approach is not listed in Table 1, because it is really not an emission control technique.

TABLE 1.—SUMMARY OF CONTROL ALTERNATIVES FOR SO<sub>2</sub>

Control technique	Sulfur removal efficiency (3 percent S base), percent	Energy penalty, percent	Incremental cost, milts per kilowatt-hour	Timing	Annual capacity, 10 <sup>6</sup> tons coal	Likely applicability	Other environmental effects	Comments
Nonregenerable (lime/limestone) scrubbing (new plants).	90	3-7	3.0	1975-77	230/(1980)	All new utilities and large industrial boilers.	Waste disposal problems.	Operation load factor 80 percent, 1,000 MW powerplant.
Nonregenerable scrubbing (existing plants).	90	3-7	4.4-6.1	1975-77	60/(1980)	Boilers ≥ 100 MW ≥ 20 yr age.	do	Operating load factor 600, 300 MW powerplant.
Regenerable scrubbing (new plants)	80-85	3-7	3.4-7.0	1980		New util ties and large industrial boilers.	Reduced waste disposal problems.	Limited data on utilization and costs.
Physical coal cleaning	30-50	3-10	.6-1.6	1974-80		All coal combustors.	Land, air, waste disposal at cleaning site.	Cleaning costs \$1.50/ton.
Coal liquefaction (solvent refined cleaning).	75-85	20	10	1985	110	Existing and mine mouth powerplants, industrial boilers, small point sources.	Sulfur and other emissions partially concentrated at central plants; increased mining necessary, untidified air, water, and solid waste problems	Economics of scale possible.
Low-Btu gas	80-88	10-40	6-16	1980-85/1980	13/200	New and large existing powerplants		Energy penalty reduced by combined cycle application. Capital intensive.
Pipeline quality gas	98+	40	NA	1980/1985	29/50-100	Small and area sources		Minimal energy penalty if used to replace electric heat.
Fluidized bed	90+	(*)	0-3	1985	150	New powerplants and industrial boilers.	Substantial reductions in NO <sub>x</sub> emissions possible.	Energy efficiency can be greater than conventional powerplants.
Refuse combustion	20	(*)	(*)	1985-90	50	Coal mix, 10 to 20 reuse.	Benefits due to solid waste reduction.	
Low sulfur western coals	75-85	(*)	0-5.3	1980	250	Western and fringe eastern boilers.	Increased particulate control necessary.	3% energy penalty for transportation to eastern areas.
SIP compliance coal (Eastern)	33-70	(*)	1.0-3.0	1975	95	Eastern existing boilers.		Cost for 1% S or less compared to 3% S coal.
Desulfurized residual oil 0.3	85		2.0	1980-85	NA	Existing oil burners.	Also removes V, other trace elements.	

\* Minimal.



The use of low sulfur coal is conceptually the simplest option for sulfur dioxide limitation. Problems of transportation from the West to the East remain to be worked out, as do policies on strip mining. Limitations on supply capacity and the fact that low sulfur coals command a higher price than high sulfur coal combine to make this option less attractive in the Commerce report (10) than other options, e.g., the combined beneficiation and flue gas desulfurization mentioned above.

In flue gas desulfurization processes, the flue gases are chemically reacted with a reagent such as lime or limestone to form a precipitate or sludge. The method can remove 90% of the sulfur oxides in the flue gases. There are different approaches to the reagent and sludge handling. In one, called non-regenerable scrubbing, an inexpensive reagent like lime is chosen, and the sludge must be disposed of as a solid waste. This in itself, of course, poses some environmental and operational problems and counts as a debit in the analysis of the method. There were initially strong criticisms of the method because of large down times experienced at some installations. However, as personnel knowledgeable in chemical methods have been incorporated into utilities' staffing, these problems have largely disappeared. Further improvement can be expected as the utilities develop the experienced staffs of chemical engineers for the operation of these chemical processes. Another approach to scrubbing involves choice of a more expensive reagent such as magnesium oxide. In this process, the sludge can be treated to yield sulfuric acid and regenerated reagent. One thus has a second useful product, and the solid waste problem is obviated. The first demonstration plant using this method has been run, and a second has begun initial operation. Sulfuric acid is heavily used in the fertilizer industry, but because of shipping costs is normally manufactured from elemental sulfur near the fertilizer plant. Proper development of the markets for the acid product is an important part of making regenerable scrubbing attractive.

Fluidized bed combustion is one of the advanced approaches that appears particularly attractive at this point. Sulfur removal is very high, there is negligible or no energy penalty, and there is promise of reduced nitrogen oxide emissions. Tests have shown this approach to work, but much additional research and development is required before it can be considered a commercial option for new plants. Conceptually, the approach is similar to the lime scrubbing flue gas desulfurization, except that the sulfur oxides are removed in the boiler instead of in the stack. Limestone is mixed with the coal, and the sulfur oxides formed by the combustion reacts with the lime to form solid calcium sulfates which can be removed with the ash.

In summary, use of low sulfur coal, flue gas desulfurization, or a combination of coal cleaning and flue gas desulfurization are all well developed options for sulfur dioxide control. More advanced systems are being worked on. However, control of sulfates in the atmosphere may not depend only on control of sulfur dioxide, but may depend on control of precursors such as oxidants and nitrogen oxides—it may even depend on cleaning up polluted waters. Much knowledge is needed on sources, formation, and transport before control options for sulfates from stationary sources can be treated in a rational way.

### *Mobile Sources*

Most gasolines contain several hundredths percent by weight of sulfur. In normal automotive combustion this is oxidized to form sulfur dioxide which is emitted with the other exhaust gases and then mixed in the atmosphere. The amount of sulfur dioxide directly from automotive sources accounts for only about 0.6% of man's contribution to the atmospheric sulfur oxide load, and only about 0.25% of the total sulfur oxides burden when natural sources are also considered. This low direct contribution of auto exhausts to the total sulfur oxides burden in the atmosphere appears insignificant. However, there may be a very much larger indirect contribution from automobile exhaust gases. As noted in the discussions above, the conversion of sulfur dioxide to sulfates may depend on such things as the concentration of photochemical oxidants. Oxidant concentrations depend in turn on automobile emissions. Thus, high HC/CO/NO<sub>x</sub> emissions from cars could lead to more conversion of sulfur dioxide to sulfates, and hence to a higher concentration of sulfates in the atmosphere. In some locations, as discussed earlier, oxidant concentrations may even be the limiting factor in the determination of sulfate concentrations.

When catalytic converters are used to reduce auto emissions, the sulfur which normally would have come out as SO<sub>2</sub> is chemically transformed in the converter to form sulfuric acid. This acid is emitted as a very fine aerosol in the respirable size range, thus posing a potential health problem. Though in hindsight this potential problem should have been obvious to scientists and officials from the start of the converter program, it was not until 1973 when Ford Motor Company called attention to it that there was any action on it. To start with, measurements could not readily be made because instrumentation for sulfuric acid aerosol was very inadequate. Further, one wanted to determine what the ambient exposures to acid aerosol would be assuming all autos were built with catalytic converters. Assessing the problem thus required mathematical modeling of aerosol concentrations and the use of a number of estimates. Initial results of such efforts by EPA scientists for estimates of near-road concentrations indicated that alarming levels of the acid might be in and near the roadway. More refined calculations in the past two years have led to concentration estimates many times smaller than EPA originally estimated. In October of 1975, General Motors with EPA and other invited participants conducted an ambitious experiment at the G.M. Michigan proving ground. They equipped about 350 cars with the "extra-air" type of catalytic converter now used on cars in California and operated them simultaneously to simulate very heavy traffic, and hence "adverse conditions" for possible sulfuric acid buildup. Results from those tests are not yet published. EPA used a newly developed instrument for measuring sulfuric acid concentrations, and unofficial data indicate on-road increases of sulfuric acid concentrations of only 3-6 micrograms per cubic meter.

This is about 100 times less than EPA had originally predicted, but it may still present some local health problems. The 94th Congress is considering amendments to the Clean Air Act which would postpone and relax emission standards for automobiles in order to aid in the development of better fuel economy for cars and to avoid the sulfuric



acid "problem." In considering a possible change in auto emission standards one would like to know which control strategy leads to less severe health effects. That is, do relatively high HC/CO/NO<sub>x</sub> emissions lead to photochemical oxidants which are harmful in themselves and which are believed to oxidize sulfur dioxides to more harmful sulfate; or is the direct emissions of sulfuric acid aerosol (a specific sulfate) more harmful? The accounting is not simple, and the chemistry of conversion of sulfur dioxide to sulfate is not well enough understood to answer the question of precisely how much additional sulfates one gets as a result of relatively uncontrolled precursors.

The most straightforward solution to emission of sulfuric acid from cars is to desulfurize the gasoline. The technology is known, and estimates are that sulfur content in gasoline could be brought from an average of 300 parts per million to 100 parts per million at a cost of 1 to 2 cents per gallon to the consumer. Other options include use of dual or three way catalyst systems or use of sulfate traps. All three of these options need more research. There is controversy (3) for instance, as to whether the dual catalyst will actually reduce sulfates, despite the fact that at least one set of tests show very good sulfate reduction. The three way catalyst operates effectively over only a very narrow range of exhaust conditions, and sensors and controls (simple computer) need to be worked out to keep proper conditions as the car ages. Still other approaches to control HC/CO/NO<sub>x</sub> include development of different approaches to the internal combustion engine such as the stratified charge engine and advanced development of others such as the Stirling, Brayton, or diesel engines.

### *Health Effects*

Adverse health effects from air pollution have been documented from air pollution episodes and industrial exposure situations. Such episodes date from the nineteenth century through the present. The data from these episodes are quite useful in correlating increased, morbidity and mortality with very high levels of pollution, but contribute little to indicating the consequences of lower level exposures, or of establishing effects of specific pollutants. They help to establish that pollution is bad for human health, but do little to quantify the concept.

Directed research during the past two decades has helped to clarify the situation somewhat. Research efforts have taken the form of epidemiology (human population studies), clinical studies (controlled experiments on human subjects), and toxicology (controlled experiments on animals). The controlled experiments, of course, are much more able to demonstrate cause-effect, and to attach quantitative dose values to the measurements. The clinical studies, however, are limited primarily to studying healthy subjects, and exposure times, etc., are limited for practical reasons. For toxicology, there is always the problem of not knowing precisely how to transfer results on animals to humans or how aggravation of acute symptoms relates to aggravation of chronic symptoms. In principle, epidemiology yields data on lower exposures for the full population—including special risk populations—but it proves very difficult to get data in sufficient quantity and of high enough quality to be meaningful. Thus, in epidemio-

logical research, one must gather health data on populations with varying levels of exposure to pollutants.

A moment's thought emphasizes that it is not easy to quantify how sick is sick, nor is it possible to make all other health-influencing factors (diet, smoking, rest, exposure to disease, mental health, etc.) the same for the people studied. If only small differences (or gradients) in exposure to pollutants can be studied, which is usually the case, one must use large populations in order to be able to correlate health effects differences with the different exposures. Further, sophisticated statistical analysis of the data is needed for interpretation. The EPA conducted a national program of standardized epidemiological studies designed to measure simultaneously environmental quality and sensitive health indicators in sets of communities representing gradients of exposure to common air pollutants. This program, Community Health and Environmental Surveillance System (CHESS), while subject to a number of criticisms (2, 5, 6, 7) (some of which will be discussed later) has yielded a certain amount of approximate data on health damage by sulfates to the susceptible or at-risk populations including children, elderly, and those with chronic pulmonary or cardiac problems. "Best judgment estimates" of pollutant thresholds for adverse health effects of both long and short term exposures were given by the investigators, and are shown in Table 2 taken from Reference 9.

TABLE 2.—RESULTS OF EPIDEMIOLOGICAL STUDIES

Adverse health effect	Concentration* at which effect was observed			Averaging time
	SO <sub>2</sub>			
	μg/m <sup>3</sup>	Parts per million	Sulfates, μg/m <sup>3</sup>	
Increased mortality.....	300-400	(0.11-0.15)	NA†	24 hr.
Aggravation of symptoms in elderly.....	365	(.14)	8-10	Do.
Aggravation of asthma.....	180-250	(.07-.09)	6-10	Do.
Decreased lung function in children.....	220	(.075)	11	Annual mean.
Increased acute lower respiratory disease in families.....	90-100	(.034-.037)	9	Do.
Increased prevalence of chronic bronchitis.....	95	(.035)	14	Do.
Increased acute respiratory disease in families.....	106	(.039)	15	Do.
Increased respiratory disease related illness absences in female workers.....	NA†	NA†	13	Do.
Primary standard.....	365	-----	-----	24 hr.
Do.....	80	-----	-----	Annual mean.

\*Effects levels are best judgment estimates based on a synthesis of several studies.

† Not available.

Comparing the threshold concentrations of about 10 micrograms per cubic meter with maps of annual average sulfate concentrations, one notes that 24 states mostly in the Northeastern U.S. already have annual average concentrations of sulfates which surpass this. In estimating the health consequences to the approximately 125,000,000 living in this area, Dr. Carl Shy in testifying before the Subcommittee said:

"WHAT IS THE ANTICIPATED MAGNITUDE OF THE PUBLIC HEALTH HAZARD?

"To answer this question, I will make use of dose-response functions developed by EPA's National Environmental Research Center at Research Triangle Park, N.C. In this discussion, we are comparing



expected health effects if the air quality standards are achieved, with health effects resulting from meeting national electric power needs without achieving clean air standards. The results of these computations are as follows:

ESTIMATES OF ADVERSE HEALTH EFFECTS ATTRIBUTABLE TO SULFUR OXIDE EXPOSURE IN THE EASTERN UNITED STATES

Adverse health effects	Estimate of illness attributed to acid sulfates			
	Standards met		Standards not met	
	1975	1980	1975	1980
Million days of aggravated heart and lung disease.....	5.3	1.2	24.4	33.8
Increased number (millions) of asthma attacks.....	2.5	.8	8.8	11.5
Thousands of lower respiratory diseases in children.....	48	0	486	888

"I wish to make 2 important points from these data. If the air quality standards are met and we reduce population exposure to acid sulfates, we can anticipate substantial health benefits for large segments of the population. We may expect a 67 to 77 percent reduction in the amount of acute illness aggravation (asthma and heart-lung disease) attributable to acid sulfates in the atmosphere, and this reduction represents an estimated 5 million illness episodes among a population-at-risk of about 8 million persons. Of course there will be other causes of acute illness aggravation, and thus we do not claim that air pollution control will eliminate these health problems. However, extrapolations from our dose-response functions suggest a large public health benefit from continued implementation of air quality control strategies.

"Secondly, our computations suggest a very large public health penalty associated with failure to meet the standards. By 1980, we are talking about 32.8 million excess episodes of aggravated heart and lung disease, 10.7 million excess asthmatic attacks, nearly 900 thousand and excess acute respiratory disease episodes in children. The absolute numbers are less important than the general magnitude of the excess illness. These figures represent a 4- to 20-fold increase in acute illness over 1975 levels and a much greater increase by 1980 over the illness experience if air quality standards are achieved.

"This discussion has focused on only a few of the adverse health effects associated with ambient sulfur oxides. There are many other health hazards which have shown relationships in epidemiological studies with sulfur oxides, for example, excess mortality, increased risk of chronic respiratory disease, some evidence for an increased risk of lung cancer. We could also consider the various irritating effects of sulfuric acid on nasal and respiratory mucosa, as well as damage to vegetation, soils, lakes and materials. These considerations are not only outside the focus of this discussion, but would simply magnify the estimates of the public health and welfare damage associated with the transformation products of sulfur dioxide emissions."

It should be recognized that in making the above estimates for "Standards Met," the assumption was made that sulfate concentrations are proportional to sulfur dioxide concentrations—an assumption we have already discussed as questionable. In any event, the available data and the model indicate that a large and serious health insult is occurring as a result of exposure to pollution in the atmosphere.

Criticisms of the CHESS study have come from the scientists doing the work, from the National Academy of Sciences report (2), and other works (5), (6), (7) commissioned by interest groups to critique these unique experiments. The usual first criticism points out that such epidemiological studies show an association of sulfates with health effects, rather than a causal relationship. Critics thus say that sulfates are at best an indicator of the things causing health damage. Also, the measurement methods used in the CHESS work are criticized—they measured only total water soluble sulfates with no size discrimination and no species identification. Furthermore, the particulate collection technique is criticized in that sulfates may have been formed on the filter surface from sulfur dioxide. Other criticisms point out that ragweed and other allergens were not measured and correlated. Also: Only absolute temperature and not temperature change was accounted for; there was a high turnover of people studied, with substitutions in some experiments; the statistical methods used for analysis were new and unproven; and so on. Most of the criticisms have some validity and point to the difficulty of obtaining this type of information and of the need for further and more refined research in the area. All criticism accounted for, the CHESS work still shows up a large and significant health problem for which water soluble sulfate is an indicator.

A variety of other health findings, especially some from clinical and toxicological studies, should be mentioned. The limited amount of work on controlled exposure to sulfates indicates broncho-constrictive effects at threshold concentrations of the order of 100 micrograms per cubic meter. (This is 10 or more times higher than the "best estimate" thresholds deduced from epidemiology for "at risk" populations and listed in Table 2.) Controlled studies have shown that there are synergisms between sulfur oxide pollutants and other pollutants such as ozone. Particle size plays a role in the degree of damage by sulfates, with sizes less than 1 micron being most harmful. (Note, however, that large particles can dominate a measurement technique such as collection on the filter of a hi-vol sampler. Each large particle has much more mass than the tiny respirable aerosols. Thus, particle size distinction is important in further health study.) The degree of insult from sulfate exposure has been found in some cases to depend on temperature and upon humidity. All three approaches to health effects assessment indicate stronger adverse reaction to sulfates than to sulfur dioxide acting alone. Finally, a number of scientists believe that it is the acidity of the sulfate compound and not the sulfate ion itself which is damaging.

Thus, though efforts of the past two decades have helped to clarify what the problems may be, and have indicated approximate magnitudes, the data are far from defining clear-cut dose-response functions which can be used with confidence in decisions affecting the several pollutants involved.

#### *Other Effects*

In addition to the insult to human health, sulfates have been related (2, 3, 9) to damage to ecological systems, damage to materials, degradation of visibility, and possible climate modification. Professor Ellis Cowling in testifying (3) before the Subcommittee linked sulfates



to the phenomenon of highly acidic rainfall in the Northeast. There is a close geographical correlation between acid rainfall and sulfate concentrations (of course, these also correlate with a variety of other things, so this does not prove a causal relationship). Professor Cowling noted that acidity of rain occurs with a pH of  $-3.6$  and less in the Finger Lakes area of New York State. Such acidity (comparable to that of vinegar) has been associated with decreased nitrogen fixation by plants, decreased fish reproduction in lakes, and overgrowth of peat moss on lake bottoms. Acid rain is further linked to adverse trends in productivity of some forests, and agricultural crop loss from this effect is estimated (2) at about \$200 million annually. The United States does not have a network to monitor the chemistry of precipitation. Such information as we have has been pieced together from observations made over relatively short times at scattered places and periods of time. Europe—and particularly Scandinavia—has a comprehensive monitoring network to study acid rain, and ecological effects have been more fully studied there than in the U.S.

I.C.T. Nisbet cites (2) damages to galvanized and painted steels at an annual level of several hundred million dollars (a high estimate by Gillette of \$909 million in 1968). Damages to other painted surfaces such as residences and automobiles also are estimated in the hundreds of millions of dollars range. Destruction and erosion of works of art, historic buildings, and monuments are difficult to assess quantitatively, but numerous cases are documented. An often cited example is Cleopatra's Needle in New York City which has received more damage in the few decades it has been in the U.S. than it received in all the previous centuries in Egypt.

Deterioration of the aesthetic quality of the environment by air pollution is a widespread public concern. Aesthetic damages include reduction of long distance visibility and light transmission of the atmosphere, noxious odors, soiling, and materials degradation. Of course, it is difficult to attach dollar figures to aesthetic costs, but they are very real and meaningful in determining such things as real estate values. Waddell is cited (2) with an estimate of \$5.8 billion as the annual national cost of aesthetic and soiling effects, of which 50 percent is allocated to sulfur oxides.

The extent to which sulfates, as opposed to the combination of other pollutants, are responsible for these effects is not known. Certainly nitrogen oxides also play a role in the chemistry of rain. Sulfates play a major but not exclusive role in visibility degradation and soiling.

Despite the high costs cited for the above effects, health damage is assessed by North and Merkehofer in a decision analysis of the sulfates problem to be more costly by almost a factor of 3.

### *Measurements of Sulfate Concentrations*

One part of the sulfates problem which draws little attention, because it is a "means" and not an "end," is the measurement (1) of sulfates. Typically, these measurement techniques have been cumbersome, and according to some observers, inaccurate. Of course, the meaningfulness of health studies, plume experiments, or the study of nearly any effect of sulfates depends in a very fundamental way upon the reliability of the measurements involved.



In the method usually used, the "Hi-Vol" method, large volumes of air have been pulled through fiber filters for long periods (typically 24 hours). Sample collection is followed by extraction of sulfates from the filter and measurement by one of many wet chemical methods available for determination of soluble sulfates. Typically, measurements can include the total of sulfuric acid, soluble sulfate salts, adsorbed sulfur dioxide, sulfite salts, and sulfates formed due to sampling and analytical artifacts. The last—sulfates formed due to sampling and analytical artifacts—has been of special concern. It has been shown that sulfur dioxide can convert to sulfates on the surfaces of some filters, and a variety of large particles (bugs, etc.) can influence the measurements. This is the measurement approach which has been used in the National Air Surveillance Network, and upon which such studies as the CHESS health measurements were based.

Newer sampling techniques not yet in routine use have reportedly solved such problems as the filter conversion of  $\text{SO}_2$  to sulfate and several approaches are available to provide sorting of the aerosols according to size. The "dichotomous sampler" developed by EPA is one example, and this is now being commercially produced. Sampling by size is important, because health damage seems to be worse for aerosol particles of less than 1 micron diameter. Variations of the dichotomous sampler in conjunction with flame photometry have recently been used in the laboratory as a direct means to measure sulfuric acid aerosol concentrations. There is hope that further extension of this approach can be used for measurements on a limited number of other specific sulfates found in the atmosphere and suspected to have adverse effects (such as ammonium sulfates).

To arrive at a full determination of the individual sulfate species in a sample is now a very complicated and laborious procedure, and has not been attempted more than a relatively few times. Essentially, it may involve sampling according to size, flame photometry for determination of sulfuric acid, wet chemistry to determine total soluble sulfates, and total elemental analysis by X-ray fluorescence techniques. These pieces of information are combined by a skilled analyst who attempts to deduce the original sulfate species in the sample. Techniques such as electron spectroscopy, for chemical analysis (ESCA) hold some promise for improving this situation, though such techniques are now too complicated for general field use.

### III. INFORMATION NEEDED

An attempt is made here to list things we need to know about atmospheric sulfates. No pretense is made that the list is exhaustive, but rather it is given as representative.

1. We do not have field measurement technology to obtain accurate measurements of ambient concentrations of specific sulfates.

2. We do not know for sure what the main sources of sulfates are. We do not know which specific sulfates derive from anthropogenic sources and which from natural sources. In a given area we do not know the fraction of sulfates derived from man's activities compared to total concentrations.

3. We do not understand the atmospheric chemistry and meteorology involved in conversion of sulfur dioxide and hydrogen sulfide to sulfates. We don't know the involvement of variables such as humidity, temperature, sunlight intensity, and other pollutants.

4. Primarily, because we don't understand the chemistry, we do not know what would be an effective way of controlling sulfates in the ambient atmosphere.

5. We cannot specify the health impact of exposure to given levels of specific sulfate compounds. We do not have dose-response curves for exposure to sulfates. We do not know the acute responses to exposures of populations to given sulfates, nor do we know what chronic effects are induced as a result of long term exposure to low levels of sulfates.

6. We do not know the main synergisms between sulfates and other pollutants in inducing adverse health effects. We do not know the role of temperature and humidity in increasing or decreasing the sulfates' potential for health damage.

7. We do not know the full role of sulfates in producing acid rain. We do not know the full consequences of acid rain. We do not have a monitoring capability to know what the trends of acid rain are in the country.

8. We do not know the materials damage caused by specific sulfates as opposed to other pollutants.

Basically, it amounts to the fact that our knowledge in every area is enough to help us realize there are serious problems, but not enough to allow us to proceed with the solutions.

It is interesting to note that a Workshop on Health Effects of Fossil Fuel Combustion Products, (13) sponsored by the Electric Power Research Institute, reached very similar conclusions with respect to health effects and measurement (see Appendix D).





#### IV. DISCUSSION AND FINDINGS

Considering that sulfur oxides in the atmosphere have been recognized for over a century as a probable health menace, it is agonizing that our knowledge is not more refined than outlined in Sections II and III. Certainly, the reason for this situation is not that there has been no research; for people have indeed studied the problem at varying levels of intensity for the long period cited. Why, then, isn't our understanding at a higher level, and what is being and can be done about it?

Any attempts to answer this question will, of necessity, be oversimplified. The most obvious answer to "why," is that there just has been no overall targeted program to study the sulfates. The next order question, "why hasn't there been such a program?", seems to be answered by realizing that the regulatory agencies have seemingly assumed a *de facto* regulation of sulfates by regulation of sulfur dioxide. According to Dr. John Finklea in testimony (3) before the Subcommittee, "The key problem actually began in 1967 when we decided we could use sulfur dioxide as a surrogate for all of the other [sulfur] oxides. After that we found it very difficult to change our minds." Evidence was discussed earlier that indicates that sulfate concentrations do not in general follow sulfur dioxide concentrations, which at least calls into question the policy of regulating sulfur dioxide in order to regulate sulfates. Currently, however, the EPA seems to hold onto the notion. Dr. Wilson Talley before the Subcommittee said, "Although control of sulfate precursors other than SO<sub>2</sub>, such as particulate and oxidants, may eventually prove to be an important component of sulfate control strategy, control of atmospheric sulfates will probably depend primarily on increased control of sulfur dioxide emissions."

Dr. Talley's judgment may eventually prove to be correct. However, the problem is of a large enough size, entering so intimately into the current national efforts in the energy field, that one cannot simply make the assumption of *de facto* control. One cannot relegate research on sulfates and other combustion derived pollutants to second order priority. The issues must be clarified. The research must be done. All witnesses (3) appearing before the Subcommittee emphasized the need for the research. A targeted and comprehensive research program for obtaining the needed data should be outlined and pursued with deliberate speed.

A number of agencies are, in fact, involved in research related to the sulfates issue. Both EPA and ERDA have strong statutory obligations to do the research. In designing a comprehensive plan these agencies should carefully and deliberately delineate responsibilities. The problems are so enormous that the most efficient efforts of all parties will be needed to do the job. A recent inventory (12) of energy related biomedical and environmental research showed that in fiscal year 1975 ERDA did 38.8 percent of characterization, measurement, and monitoring research compared to 25.5 percent by EPA; ERDA did 40.9 percent of environmental transport research compared to 28.7 percent by EPA; ERDA did 67.6 percent of health

effects research compared to 13.9 percent by EPA; ERDA did 34.8 percent of ecological effects research compared to 9.2 percent by EPA. The figures serve to emphasize the fact that the agencies in proceeding, should do so with delineation (not just correlation) of goals and responsibilities as pertains to the sulfates and other combustion-derived pollutants.

There are other less-general observations which should help towards a more efficient "closing of the sulfates knowledge gap." One readily recognizes that knowledge of health and welfare effects and knowledge and ability for control are no better than the knowledge and technology bases upon which they rest. These bases are: first, measurement knowledge and capability, and second, knowledge of formation and transport. For sulfates research, these bases are not strong.

Several witnesses before the Subcommittee stressed the importance of better measurement capability. The Environmental Protection Agency claims to have recognized the need for better measurement in their research. Dr. Wilson Talley, Assistant Administrator for Research and Development in EPA, in his testimony before the Subcommittee stated, "The most critical research need at this time is the development of instruments and analytical methods for determining the chemical composition and size characteristics of sulfate aerosols." The EPA "Position Paper on Regulation of Atmospheric Sulfates" (9) states, "one of the reasons that such a lengthy period (to 1980 or 1981 to get knowledge for a sulfate standard) is needed for the research program is that many of the projects cannot begin until after successful completion of other program elements. The most prominent example of this interdependency is the development of reliable monitoring methods for total sulfates, sulfuric acid, and specific sulfates. Such methods may take 1 to 3 years to develop. Important components of epidemiological, toxicological, clinical, and characterization studies are dependent on the use of such monitors. This extends the completion date of the entire effort." However, as can be seen in the accompanying table, the budget for Measurements, Instruments, and Methods Development was only \$800,000 in fiscal year 1975, or 2 percent of the sulfates related research budget. In fiscal year 1976 the budget was still \$800,000, or 3 percent of a smaller total budget. Thus, for an item which is the pacing item in an effort, the resource allocation does not appear consistent with the evaluation.

ENVIRONMENTAL PROTECTION AGENCY, OFFICE OF RESEARCH AND DEVELOPMENT, SULFATE PROGRAM  
[In thousands of dollars]

Research and development program categories	Fiscal year 1975	Fiscal year 1976
Sulfur oxides transformation and modeling.....	4,500	4,500
Ambient air monitoring.....	470	470
Measurements, instruments and method development.....	800	800
Epidemiological and chemical studies.....	2,000	2,000
Animal toxicology.....	2,800	2,600
Ecological effects.....	900	900
Catalyst program.....	2,000	2,000
Subtotal.....	13,470	14,370
Control Technology.....	25,000	11,000
Total.....	38,470	25,370

#### NOTES

1. These include EPA Energy funds but not interagency pass-through funds.
2. Catalyst dollar estimates are for the sulfate component of the total catalyst program.



The very fundamental and basic role which proper measurement needs to play in health research, formation and transport research, control evaluation, and monitoring needs to be recognized. Upon this base rest all these other more visible functions of the agency. The base should be strengthened. There should be room in the program for research to explore a variety of new, imaginative, and daring approaches to measurement—some of which may lead to failure, but some of which might lead to the breakthroughs needed. Furthermore, perhaps the agency should re-examine the cost effectiveness of deploying marginal instruments to get marginal data using moderately skilled personnel versus deploying more sophisticated instrumentation even though more expensive highly trained personnel are needed. It would seem that if in projected epidemiological studies and other work, the latter approach is more cost effective, then a case should be made to OMB and to the Congress to provide the additional resources needed.

The Population Studies Division of the Health Effects Laboratory of EPA historically developed its own instrumentation support group in order to begin needed work in a timely way. This separate group continues to be attached to the health measurements laboratory despite the fact that most of the innovative instrumentation in the Agency is developed in other divisions. One would expect that without good communication, the instrumentation and monitoring in the epidemiological work might suffer. The Assistant Administrator of Research might properly consider this situation to determine if the arrangement is leading to optimum quality measurements in the population studies.

The EPA, in cooperation with the University of North Carolina, has built some of the finest human studies facilities found anywhere in the world. These facilities will be coming on-line soon, and every effort should be made to encourage their full capacity use. The "National Facility" concept with encouraged access by research groups from around the country would help insure optimum use. These facilities should prove very valuable in the continued efforts to delineate dose-response functions for human subjects under controlled conditions.

Looking ahead two or three years to the time when instrumentation has been brought up to the level needed to accurately measure concentrations of specific compounds and to determine sizes of aerosols (including, but not limited to sulfates), a major new epidemiological study certainly will be justified. Mr. Donald Allen of the New England Electric System in his testimony before the Subcommittee called for such a study:

"It seems to me that as the research goes on in the sulfate-nitrate problem we will know more about the chemistry; we'll be able to measure things better; we'll have input. But the ultimate bottom line of what I'll call the front end answer has got to be: What are the effects on public health? And it seems to me that ultimately this can be done satisfactorily only by a very well conducted epidemiological study. The point I would like to make is this: This is a very big study; it's very complex; it's extremely costly. More than that, I think it can be put in place only at the governmental level,

basically from one of the Federal agencies, or a combination of them, and with the cooperation of the public health apparatus, all the way down to the local community. For both the reason of cost and the organization required, I see no way that a private study can be mounted which would have anything like the validity of a major public study. So I've come to my own conclusion that there probably is only going to be one, and if there is only going to be one, let it be as good as possible. Since there is only one, you want it as good as possible. I make an urgent plea that this study be a national effort, be open to anybody who can make a contribution, be accessible at all stages, and that the contributions and the suggestions of the knowledgeable community, whether it be academic or private industry, be accepted and worked in throughout the progress of the study, and, on the contrary, that the results not be withheld and announced in the press *ex post facto*."

Dr. Stanley Greenfield, in discussing before the Subcommittee the size of an epidemiological study to delineate effects of specific sulfates, said:

"We had a study, the CHESS study, is at least going on, consisting of 300,000 individuals in 32 communities, supposedly with proper controls thrown in to allow statistical evaluation. But the moment you start to stratify your sample to enable you to start to extract other pollutants, or separate the pollutants, 300,000 people disappear into a very, very small number, and you're left in the quandary that the Agency finds it's in now, in not having adequate data, adequate information, to deal with the complex pollutants that are beginning to emerge."

Thus, considering the implied magnitude of a new effort to get data on effects of specific pollutants, and for other reasons, one must seriously consider Mr. Allen's suggestion for broad participation in the experiment. In fact, considering the international interest in this problem, the study might even be considered on an international scale. At any rate, whether domestic or international, now is the time to begin careful planning if it is to be a cooperative effort of great size. Two to three years will be barely enough time to plan, and such a lead time may be necessary to obtain the funding from OMB and the Congress. In the meantime, shorter, highly targeted experiments should be done with special attention given to development and perfection of health measurement methods and criteria and to implementation, as they become available, of new measurement methods to characterize exposure.

There are some features associated with health effects studies that deserve special comment. The private sector rewards those in the medical profession at a monetary rate considerably above the Federal Civil Service pay scales. This is partly alleviated by hiring medical doctors as uniformed officers of the Public Health Service, and detailing them to various agencies such as EPA. Nevertheless, a combination of salary limitation and lack of a well planned career development



program have made it extremely difficult to attract qualified physicians to EPA. Those who have been attracted to the agency are idealistically motivated, as revealed in conversations with doctors recently hired by EPA. However, idealism can wear thin, and the number of medical personnel in the agency has declined from only about 25 at its founding five years ago, to only about 12 now. (Part of the ability to attract 25 people five years ago is attributed by some to the fact that young doctors were able to choose an agency such as EPA as an alternative to the draft. With the elimination of the draft, this "incentive" no longer exists.) The understaffing in the health area and anticipated continued decline is probably the main factor contributing to a morale problem evident in talking to health effects personnel at EPA.

Epidemiologists are a special subcategory to which the above discussion applies. The total number of well qualified epidemiologists in the entire country probably numbers only about 100, and few are being trained. The problem needs attention. A training program needs to be developed. Though epidemiologists are traditionally medical doctors, this need not be the case, and a program to train others with the necessary skills in research, statistics, and biology or medicine should be pursued by EPA, ERDA, NIOSH and other institutions concerned about the manpower available in this area.<sup>1</sup>

Studies of ecological effects of sulfates commanded \$900,000 in each year of both FY 1975 and FY 1976, representing 2% and 3% of the respective total sulfates-related research budget. This research should be maintained and vigorously pursued. In the July hearings Professor Ellis Cowling of North Carolina State University pointed out the complete lack of any broad scale monitoring which will permit assessment and understanding of the acid rain issue. His suggestion was that such monitoring could probably be integrated with existing U.S. Forest Service and other Agriculture Department monitoring activities. This appears to be an excellent possibility and should be aggressively pursued. In any event, it is necessary that some program of long term monitoring be undertaken with a commitment for long term support.

The EPA is limited by personnel ceilings so that typically 60% or more of its research work is done by extramural contracts and grants. The nature of EPA's mission is such that the contractors are given very narrow objectives to accomplish in quite restricted time ranges. A cursory inspection of contracts and grants in health and physical sciences at EPA showed large numbers of small contracts. Subcommittee staff were told that often contracts are awarded on a sole source basis because it is known that a given source "can produce" what is wanted. This set of circumstances seems to be that which could cause the extramural program to be a relatively short extension of the in-house scientists' capacity for research. In research the limiting factor is often not manpower but ideas. It would appear that the *de facto* EPA contracts policy tends to limit ideas to those generated in-house. This is unlikely to lead to optimum capitalization of the imagination and creativity of outside researchers, and it may lead

<sup>1</sup> EPA has begun advertising in national journals, trying to hire epidemiologists.



to EPA's using a rather restricted group of contractors with restricted points of view. The Assistant Administrator for the Office of Research and Development should satisfy himself that the contracts/grants policy is taking advantage of the creativity of the scientific community to the maximum extent possible.

## V. ACTION

It is concluded that there is now enough knowledge on the effects of sulfates to recognize that they are a threat to the health and welfare of the Nation. We do not know enough to quantify levels to which sulfates should be controlled to assure the health and welfare of the population, nor do we know how to control sulfates if and when we should decide on a given level. Much has been learned, but there is much more to be learned. In addition to the continued hard work of the dedicated scientists involved, there are a number of particular items which should receive attention.

1. A comprehensive and targeted program should be worked out with EPA, ERDA, and other involved agencies delineating responsibilities and objectives. The program should be vigorously pursued with strong interaction and cooperation manifest in a formal structure.

2. Measurement science and technology should have added emphasis and added resources, since measurements form the basis of the rest of the work.

3. Within EPA the coupling between the measurements groups in the Health Effects laboratories and the Physical Sciences laboratories should be examined by the Assistant Administrator for Research and Development to determine if stronger coupling is needed between these groups.

4. The EPA should: Consider operating its unique clinical studies facilities as a "national resource"; encourage 100% usage of the facility; and make it available to users throughout the country. (Examples of other such resources are found in the national accelerator labs, observatories, etc.)

5. The Assistant Administrator for the Office of Research and Development in EPA should see to it that there is a clear career development plan for staff. This has become particularly urgent for medical professionals, and arrangements might well be pursued in cooperation with the Public Health Service.

6. The Civil Service Commission or Council on Environmental Quality should investigate problems associated with the training of health effects personnel needed by the agencies for research in the environmental area. This needs particular attention with respect to epidemiologists, and a solution should be vigorously pursued.

7. The EPA and ERDA should together determine how to carry out a new, very large and "comprehensive" epidemiological study which will be justified in two or three years when measurement techniques are readied. Questions to be answered include: Should there be invited participation of interested private groups such as the Electric Power Research Institute? Should this be pushed as an international effort? In view of the large statistical base needed to get meaningful results, is it possible to get the data without a very large, cooperative effort? Is such an effort feasible from a logistical and manpower point of view?

Planning should begin immediately, and the Congress should be notified.

8. The Assistant Administrator should seek arrangements with the Department of Agriculture for cooperation to monitor and measure acid rain parameters on a long term basis.

9. The Office of Research and Development of EPA should consider alternative strategies for interesting and mobilizing the outside scientific community to address EPA's scientific problems. One area for examination is the contracts and grants policies as discussed in Section IV. An added possibility would be the establishment of a cooperative research institute. One can envision examples of institutes which could be of modest proportions, but designed to help meet a number of EPA's needs. Such an institute thus could:

(a) Interest capable key researchers in the scientific community in EPA's scientific problems;

(b) Train new, young people in the disciplines needed for research on EPA's problems—and interest them in these problems;

(c) Provide dignified visibility of EPA's research to the external scientific community;

(d) Provide a means for broadening and intellectual renewal of EPA's in-house personnel;

(e) Provide a flow of fresh ideas and viewpoints into the agency's research program.

One example of possible organization of such an institute is discussed in Appendix C.



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## APPENDIX A

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EXCERPTS FROM THE SUMMARY FROM THE NAS/NAE NATIONAL  
RESEARCH COUNCIL REPORT, "AIR QUALITY AND STATIONARY SOURCE  
EMISSION CONTROL," COMMITTEE PRINT, SERIAL 94-4, COMMITTEE  
ON PUBLIC WORKS, U.S. SENATE, MARCH 1975

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This summary highlights the principal findings and conclusions of the report. The reader is encouraged to examine the basis for each of the findings and conclusions as it is presented in detail in the body of the report.

## SUMMARY OF PART 1: HEALTH AND ECOLOGICAL EFFECTS OF SULFUR DIOXIDE AND SULFATES

1. Adverse consequences to health from combustion of sulfur-containing fossil fuels cannot be simply ascribed to any one sulfur oxide acting alone. (The term sulfur oxide is used to mean the family of compounds including sulfur dioxide, sulfur trioxide, sulfuric acid, and various sulfate salts. Sulfur dioxide is the main sulfur oxide directly emitted by fossil fuel combustion.) Sulfur dioxide itself appears unlikely to be the direct cause of excess morbidity and mortality associated with stationary source fossil fuel combustion. However, levels of sulfur dioxide close to the current ambient air quality standards may be responsible for deleterious effects on health when inhaled in combination with respirable (very small) particulate matter or the oxidant air pollutant ozone. Oxidation products of sulfur dioxide, including sulfuric acid and suspended particulate sulfates, are more toxic than the parent compound and appear likely to be responsible for a substantial portion of adverse effects on health associated with stationary source combustion of fossil fuels. (See Chapter 3.)

2. The processes governing the conversion in the atmosphere of sulfur dioxide to sulfuric acid and suspended sulfates are complex and incompletely understood. It is clear, however, that the oxidation of sulfur dioxide is accelerated in the presence of other pollutants, particularly trace metals derived mainly from stationary source fossil fuel combustion, and components of photochemical smog derived primarily from automotive emissions. (See Chapter 2.)

3. The specific chemical species responsible for toxicity have not been identified, and the levels of pollutants necessary to cause toxic effects have not been determined. This hampers the exact determination of the morbidity and mortality resulting from sulfur oxides. The use in epidemiological correlations of monitoring data for total suspended particulates and sulfur dioxide has undoubtedly led to imprecision inasmuch as these two measurements do not directly assay the causative agents. It is possible that the use of these indicators may have led to underestimation or overestimation of the health consequences of sulfur oxide or respirable particulate matter, but most likely underestimation. Particles in the respirable size range undoubtedly play a role in morbidity. (See Chapter 2.)

4. In the next few years additional information will probably be available that will permit establishment of rational air quality standards for respirable particulate matter and suspended sulfates in order to protect the public. This will require substantial advances in monitoring and analytical techniques as well as improved assessment of health hazards. (See Chapter 2.)



5. Review of the available data suggests that it is reasonable to predict that an increase in morbidity and mortality of susceptible individuals would result from an increase in ambient sulfur dioxide to levels appreciably above the current air quality standard. (At present, levels generally do not exceed this standard.) Susceptible groups represent a substantial fraction of the U.S. population and include children, the elderly, asthmatics, and individuals with chronic cardiovascular and pulmonary disease. (See Chapter 4.)

6. In view of the societal and economic impact of controlling sulfur oxide emissions, it is of major importance to quantify the health effects associated with sulfur oxides and the benefits to be gained by avoiding those effects. A number of attempts to do so have been made, and they are reviewed in this report. Analysis of data developed from the CHESS studies of the Environmental Protection Agency provides some guidance in defining the limits of the problem, but these and other currently available data on the health effects of sulfur oxides should be viewed with caution. (See Chapter 4.)

7. Definition of a no-effect level (threshold) for the acute effects of sulfur oxides is difficult. It is not clear that there is any level of these pollutants above background that will not have an acute effect on the most susceptible individuals. However, it is beyond present knowledge to state whether acute responses to low levels are non-injurious adaptive responses or are responses which, often repeated, might lead to eventual respiratory impairment. High priority should be given to research evaluating the long-term physiological effects of sulfur oxide air pollution. (See Chapter 2.)

8. Sulfur oxide emissions from catalyst-equipped automobiles may take the form of sulfuric acid mist or suspended sulfates. Since the emissions are at ground level, they are likely to be encountered by individuals. If an increasing proportion of the automobile fleet is catalyst equipped, these sulfur oxide emissions may constitute an appreciable part of the total sulfur oxides inhaled and a significant proportion of the threat to health from these compounds. As yet there are no direct experimental data on the health effects of the particular sulfur oxides emitted from automobiles. In the absence of experience and sufficient data, we are unprepared to compare quantitatively the possible deleterious health effects arising from catalyst operation with the health benefits to be gained by the oxidation of hydrocarbons and carbon monoxide in automotive emissions. (See Chapter 2.)

9. The visible direct effects of high concentrations of sulfur dioxide on susceptible species of plants have been recognized for many years. Knowledge of whether lower concentrations decrease productivity of natural flora and fauna is very meager. The ecological consequences of the increasing acidity of precipitation deserve thorough study. The increase in acidity of precipitation appears to be related to increased emissions of sulfur dioxide and nitrogen dioxide although the exact relationship needs further study. (See Chapter 5.)

10. Identifiable effects of acid precipitation include acidification of soils, reduction in forest productivity, and depletion of fresh water fish populations. Materials, buildings, and various substances are degraded by sulfur oxides in the air and by acid precipitation. The full impact of these effects may not be felt for a number of years.

Rough estimates of their likely magnitude suggest that they are relatively modest in economic terms, but they may also involve loss of recreational opportunity and aesthetic values. The possibility of additional effects, such as reduction in agricultural productivity or extensive injury to valuable ornamental plants, cannot be dismissed. (See Chapter 5.)

11. Atmospheric hazes, attributable in large part to fine particulates including sulfates, are widespread in the eastern United States during the summer; their frequency appears to be increasing as emissions increase, and they may have effects on weather and climate. (See Chapter 5.)

12. With the protection of human health as the goal, it is desirable to limit the atmospheric emission of sulfur oxides and respirable particulate matter. (See Chapter 4.)

## SUMMARY OF PART 2. STRATEGIES FOR CONTROLLING SULFUR-RELATED POWER PLANT EMISSIONS

### SULFUR OXIDE EMISSIONS AND ABATEMENT TECHNIQUES

#### *Reasons for Reducing Emissions of Sulfur Oxides*

1. Part One of this report points out that adverse consequences to health from combustion of sulfur-containing fossil fuels cannot be ascribed to any single oxide acting alone, and that sulfur dioxide itself appears unlikely to be the sole cause of excess morbidity and mortality associated with pollution in the form of sulfur oxides and suspended particulate matter. In particular, certain oxidation products of sulfur dioxide, including sulfuric acid and certain suspended particulate sulfates, are more toxic than the parent compound and may be responsible for a substantial portion of the adverse health effects associated with sulfur oxides and particulate pollution, a portion of which arises from stationary source combustion of fossil fuels. In the study of control strategies in Part Two of this report, the concentration of airborne particulate sulfates has been used as an index of pollution hazard. (See Part I.)

2. Within a large region such as the northeastern United States particulate sulfate concentrations in the atmosphere are related to regional emissions of sulfur dioxide, which is converted to sulfates after emission. Because sulfur dioxide and sulfates may be transported long distances before being removed from the atmosphere, and because during the transport period there is conversion of sulfur dioxide to sulfates, there is not always a close relationship between ambient concentrations of sulfates and emissions of sulfur dioxide in the immediate vicinity. For example, in some rural areas in the Northeast where there are comparatively low sulfur dioxide emissions and low ambient sulfur dioxide levels, ambient sulfate concentrations are substantially above background levels. (See Chapter 6.)

3. Concentrations of sulfates in airborne particulate matter are difficult to measure but appear to have increased. The amounts of sulfates deposited in rainfall have been increasing in parallel with the increase of emissions of sulfur dioxide. The acidity of precipitation in the eastern states has also been increasing; this is attributable to an increase in emissions of both sulfur dioxide and nitrogen oxides. (See Chapters 6 and 7.)



4. In addition to the adverse effects on health from these pollutants, there are damages to materials, decreases in property values, and impairment of agriculture, forestry, and ecosystems. These effects point to the desirability of controlling the amount of man-produced sulfur compounds emitted into the atmosphere. (See Chapters 5 and 7, and Appendix 13-E.)

*Power Plants a Major Source of Sulfur Oxide Emissions*

5. Steam electric generating plants that burn coal are major sources of sulfur oxide emissions, especially in the northeastern U.S. In this region, the quantity of anthropogenic sulfur oxides almost certainly exceeds the amount emitted from natural sources such as decaying vegetation. On a nationwide basis, more than 50 percent of total anthropogenic sulfur oxide emissions are produced through combustion of coal in power plants; in some regions the percentage is much higher. Other sources of sulfur oxides include space heaters, smelters, and industrial boilers. Information recently brought to the Committee's attention suggests that oil-fired combustion, particularly in small combustion devices such as home furnaces, appears to be an important source of sulfuric acid emissions. Coal fired electrical generation may increase as much as 100 percent, possibly more, over the next decade. The resulting power plant emissions, if not controlled, may lead to increases in ambient sulfate levels in urban areas on the order of 10 to 40 percent as well as to increases in ambient sulfur dioxide levels and in the acidity of precipitation. (See Chapters 6 and 7, and Appendix 11-A.)

*Emissions from Power Plants Depend in Part on the Use of Electricity, Which Depends on Many Factors*

6. The Review Committee recognizes the national determination to decrease U.S. dependence upon imported petroleum fuels. Achievement of this goal is likely to entail a substantial increase in the use of coal for the generation of electricity. There are two reasons for this: more electricity will be required to permit reductions in the use of oil, and a larger fraction of the electricity produced will be generated from coal. The shortage of natural gas will also result in increased use of coal for the same reasons. The consequence of these changes could be a large increase in sulfur dioxide emissions. (See Chapter 6.)

7. A major current use of oil and gas is for domestic and office space heating. Electrical energy could replace the direct use of oil and gas for space heating, but this could result in additional burning of coal and accompanying emissions of sulfur oxides. Therefore, if such a change were contemplated, it would be desirable to employ space heating technology which would make efficient use of electricity. A shift to the use of electrical resistance heating would increase the overall consumption of fuel; however, there would be little, if any, increase in the overall consumption of fuel if the shift were, instead, to electrically-powered heat pumps, where local weather conditions make this technically possible. Moreover, it is estimated that the total capital investment (at the point of generation as well as at the point of use) required for the heat pump system is less than that for the electrical resistance heating system. The alternative of producing combustible gas from coal to serve the heating market also appears to require substantially less capital and less total fuel consumption than electrical resistance



heating. There are additional options for meeting some of the nation's space and water heating requirements, e.g., solar energy and possible new domestic petroleum and gas resources. Although each of these options will probably take at least three to five years before it can add significantly to incremental supplies, an examination of them should be included in a comprehensive analysis. (See Chapter 9.)

8. Conservation and improved fuel use can substantially reduce the rate of growth in demand for electrical energy and in this way reduce the amount of coal used and the sulfur dioxide emitted in its generation. Improvements in fuel use can be accomplished by: (1) improved effectiveness of electrical apparatus used in the residential, commercial, and industrial sectors; and (2) on-site generation of electricity as a by-product of certain industrial processes. (See Chapter 9.)

9. In a market economy, where consumption decisions are made by individual purchasers, economic efficiency requires that the price reflect the incremental cost of supply to society. This means, in an expanding industry, that price should equal the cost of obtaining new or replacement supplies of the resource, including social and environmental costs. If such prices are not charged, then either too much or too little of the resource will be used in relation to other resources. The rate at which fuel-saving technology will actually be applied depends upon the rate of pay-back for capital invested in such technology. One critical factor currently retarding the application of new and more efficient technology is the manner in which fuel and electricity costs are determined. The price a user pays for energy is generally based on average costs of production rather than on incremental costs, which tend to be much higher. Similarly, the higher cost of supplying electricity during hours of peak system demand is not sufficiently reflected in rate structures. A fuller application to electricity rates of these incremental cost pricing principles could make a substantial contribution to conservation and thereby to reducing sulfur oxide emissions. (See Chapter 8.)

#### *Flue Gas Desulfurization (FGD) Technology*

10. For power plants that burn low-sulfur (less than 1 percent sulfur) coal, either lime or limestone scrubbing is the most effective method now available for reducing emissions of sulfur dioxide in flue gases. Emissions of sulfur dioxide from such sources can be reduced by at least 90 percent with these methods. Successful operation has been demonstrated on commercial scale modules of 115 Mw for lime scrubbing and 170 Mw for limestone scrubbing. (See Chapter 11.)

11. For power plants that burn medium or high-sulfur coal, lime scrubbing is the most effective near-term method for reducing emissions of sulfur dioxide in flue gases. Reductions of at least 90 percent have been achieved with this method. Successful operation of a lime scrubber in the desirable closed loop mode (i.e., with no release to the environment of water from the process) in a power plant burning medium-sulfur, low-chlorine coal has been demonstrated on a commercial scale. The demonstration power plant is a peaking unit producing flue gas equivalent to about 100 Mw capacity. Although it ordinarily operates intermittently, in these trials it has operated continuously, following changes in load typical of many utility boilers. The 100 Mw

size is typical of the module that designers may provide in multiples for dealing with the flue gas from boilers of much larger capacity. The chlorine content of coal affects successful scrubber operations for at least three reasons: (1) it contributes to the acidity of sludge slurries; (2) it retards the rate of oxidation of calcium sulfite to calcium sulfate in slurries; and (3) it leads to materials corrosion in stack equipment as a result of hydrogen chloride formation. Successful operation of a lime scrubber on flue gases arising from the burning of a high-sulfur coal of medium or high chlorine content has been observed on a bench and pilot-plant scale (1.0 and 10 Mw equivalent capacity), also in a closed-loop mode. Experience on a commercial scale can and should be obtained quickly for medium- and high-sulfur coals containing chlorine beyond 0.04 percent. This experience is necessary to resolve the question of the commercial availability of lime scrubbing technology for all coals. That this question will be resolved favorably is a matter for engineering judgment in light of the available chemical knowledge and performance comparisons. Some of the Committee members judge the probability to be 90 percent, while one member judges it to be 70 percent. (See Chapter 11.)

12. The Committee is well aware of the problems which have been experienced in early installations of flue gas desulfurization processes. This discouraging experience has caused many in the electric utility industry, as well as others, to doubt the feasibility of the technology. The Committee finds, however, that there has been rapid advance in the understanding and application of scrubbing technology especially in the past year, and urges those who are skeptical to review this recent experience. If scrubbers ordered today are to operate as reliably as other components of the power generating system, they will require very careful engineering and initial "trouble shooting" operating procedures which may be extensive. There is a reasonable expectation that, in the near future, scrubbers will be available for purchase as routine components of power systems covering a wide range of specific conditions, provided a vigorous development program is pursued. (See Chapter 11.)

13. The large quantity of waste by-product associated with lime and limestone scrubbing is a disadvantage of these processes. Sludge storage using lined ponds has been successful for lime and limestone flue gas desulfurization installations. The availability of space near the power plant is an important factor in determining the feasibility of sludge storage using lined ponds and may substantially increase the cost of retrofitting plants already located in urban areas because of the need for transportation of sludge. The problem of ultimate disposal is being attacked by fixation of sludge to produce a material of low permeability and leachability, suitable for landfill and as a base for roads. Tests on commercial-scale modules are now underway in several locations. The results are reported to be promising (See Chapter 11.)

14. Installation of a lime scrubbing process for a new power plant burning high-sulfur eastern coal will require an added capital investment of about \$100/kw (all costs in 1974 dollars). The investment could be as low as \$60/kw and as high as \$130/kw. Added operating costs, including capital charges, will range from 2 to 5 mills/kwh plus a cost of about 1 mill/kwh for energy loss and capacity derating. This



is 15 to 30 percent of the total cost of generating power at a new plant. Sludge fixation, or sludge transportation, if needed, will add to these costs. (See Chapters 11 and 13.)

15. A longer term approach to the problem of sulfur emissions involves conversion of the sulfur dioxide into elemental sulfur and regeneration of the scrubbing liquor. This would eliminate the problem of disposal of large quantities of sulfites and sulfates of lime and, instead, provide easily stored and commercially valuable elemental sulfur. There is successful commercial operating experience with regenerable flue gas desulfurization processes on stack gases arising from the combustion of oil. There is no commercial operating experience using a regenerable process to treat stack gases arising from combustion of high-sulfur coal. A few such plants are under construction, and large-scale plant testing of such systems is now underway. Because the potential advantages of regenerative processes are significant, a careful evaluation of the desirability of increasing the funds being devoted to their development is warranted. (See Chapter 11.)

16. About 70 percent of existing plant capacity may be retrofitted with lime or limestone FGD systems. The cost of retrofitting is normally 25 to 30 percent higher than the cost of installing scrubbers on a new plant of equal capacity. Older, smaller existing plants are more difficult and costly to retrofit than newer, larger existing plants. (See Chapter 11.)

#### *Use of Low-Sulfur Coal and Washing of High-Sulfur Coal*

17. Most of the coal from eastern resources has a high sulfur content. Of the more limited eastern low-sulfur coal, a large fraction is held by owners who have dedicated these resources to metallurgical use. Washing of the high-sulfur eastern coals could, on average, reduce their sulfur content by about 40 percent (i.e., from a sulfur content by 3.5 percent to 2.1 percent). The amount of such reduction depends on the characteristics of the particular coal used. Coal washing will be of some benefit in reducing emissions of sulfur oxides. Conventional physical cleaning will reduce the total sulfur emitted by power plants by significant amounts (of the order of 40 percent overall) but it will not, in general, result in coals with a sulfur content meeting the New Source Performance Standards for  $\text{SO}_x$ . However, coal preparation can reduce the sulfur content to levels that are permitted by the State Implementation Plans for existing plants in some rural areas. (See Chapter 10.)

18. Large quantities of low-sulfur coal are found in the western U.S. Although new plants can be designed to burn these coals efficiently, in existing plants the boilers must be derated (i.e., operate at less than design capacity) to operate satisfactorily. Moreover, the transport of low-sulfur western coals to eastern markets will require construction of major additional transport facilities. (See Chapter 10.)

19. By shifting available low-sulfur coal away from plants that could burn higher sulfur coal and still meet ambient sulfur dioxide standards to plants in regions not meeting ambient standards for sulfur dioxide, some improvement in compliance with applicable ambient air quality standards for sulfur dioxide could be achieved. However, such shifting of low-sulfur coal will not reduce the total amount of sulfur in the atmosphere; therefore, this strategy should be considered at best an interim measure only. The potential for increasing ambient sulfate



concentrations in downwind areas should be carefully assessed before any such strategy is implemented. (See Chapters 6, 7, 10, and 13.)

20. Caution must be exercised in the substitution of low-sulfur coal in existing power plants, since there is a resultant risk of increasing emissions and ambient concentrations of particulate matter. The efficiency of devices for the removal of particulate matter, especially electrostatic precipitators, is decreased for fly ash from low-sulfur coals. Hence, a decrease in sulfur dioxide by fuel substitution may result in greater emissions of particulate matter, including any trace metals present in the coal. Such problems could be minimized by appropriate modification of equipment or process conditions or both. (See Chapter 10.)

#### *Tall Stacks and Intermittent Control Systems (ICS)*

21. Tall stacks and/or intermittent control systems make it possible to meet ambient sulfur dioxide standards in carefully defined situations. The attractiveness of these systems lies in their low operating and capital costs, estimated to be 0.15 to 0.4 mill/kwh and \$4 to \$10/kw, respectively. The Committee does not recommend their use unless it is for carefully defined situations for an interim period until other strategies (e.g., flue gas desulfurization, low-sulfur fuel) can be implemented, or until further data are accumulated which would justify making them permanent. The application of tall stacks and/or intermittent control systems will not reduce total emissions of sulfur oxides to any significant degree; thus, this strategy does not decrease the total amount of sulfate in the regional atmosphere. The potential for increasing ambient sulfate concentrations in downwind areas should be carefully considered in advance, and effects on ambient concentrations monitored, if such a strategy is implemented. (See Chapter 12.)

#### *Recommended Decisions and Decision Processes for Abatement Strategies*

22. Methodology is available for analyzing decisions among abatement alternatives: the deleterious consequences of sulfur oxide emissions to human health, ecological systems, material property, and aesthetic values should be evaluated and compared (for each power plant in a region) with the additional cost imposed on the generation of its electricity by the abatement methods. The calculation thus involves a comparison of marginal cost with marginal benefit for each power plant within the regional system of electric generation and air quality. However, conclusions drawn from the application of this methodology must of necessity reflect the adequacy of the information available at the time of application; at the present time uncertainty in many critical variables and relationships severely limits the conclusions that can be drawn as to the best strategy alternatives for controlling sulfur oxide emissions. By assessing in probabilistic terms the respective costs and benefits for various alternative strategies, the methodology can indicate where, on the basis of the limited information available, stringent control is desirable and where more information would be advisable before a commitment to a particular emissions control strategy is made. (See Chapter 13.)

23. There are considerable uncertainties concerning the extent of the harmful effects of sulfur oxide emissions, and concerning the specific relationships between point source emissions of sulfur dioxide

and regional patterns of formation, dispersion, and deposition of sulfates. Any policy adopted now, therefore, should be reviewed periodically in the future and may have to be changed as a result of new findings. Nevertheless, the calculations shown in Chapter 13 suggest that the benefits of abating emissions of sulfur oxide may exceed the costs substantially for plants which affect areas where there are already high ambient concentrations of sulfur dioxide and suspended sulfates, such as urban areas in the Northeast. In addition, the Committee places importance on considerations of prudence; the consequences of an error in judgment which led to substantial damage to human health would be more serious than an error which led to an economic misallocation. Accordingly, the Committee recommends that high priority should be given to emission abatement from power plants in and close upwind of urban areas. Although the analysis in Chapter 13 indicates that lower priority should be given to power plants far (of the order of 300 miles) upwind from major cities, it also indicates that external costs imposed by emissions from these plants may be substantial. Since the capacity for installing flue gas desulfurization systems is limited, there will be a continuing opportunity to review the costs and benefits of emission controls for plants now assigned to a low priority. (See Chapter 13.)

24. National capacity to produce stack gas scrubbing equipment is limited. Further advances in applicable technology are expected to occur in the next few years. Scrubbing equipment should be installed first in those situations where its additional benefits in emissions abatement are judged to be highest with respect to its additional costs. All new plants, including those able to meet New Source Performance Standards without the use of scrubbers, should at least be constructed so as to permit subsequent retrofitting of flue gas desulfurization systems, since the cost of allocating space for that purpose is low. In time, the increase in coal use and further information on the effects of sulfur oxide emissions may indicate a need for a greater degree of emissions reduction. (See Chapter 13.)

*The Value of Resolving Uncertainties on the Effects of Sulfur Oxide Emissions*

25. Decisions about control strategies depend upon the information available at the time the decisions are made. A better understanding of the effects of suspended sulfates on health and of the chemistry of the atmospheric conversion of sulfur dioxide to sulfate could have a significant effect upon future decisions about sulfur oxide emissions abatement. Improving the available information about these aspects of sulfur emissions has an expected value on the order of hundreds of millions of dollars a year, which is at least ten times greater than the cost of a research program to resolve these uncertainties in approximately five years. (See Chapter 13.)

26. Current assessments of the benefits of sulfur oxide emissions reduction for human health, ecological systems, materials, and aesthetic values could be greatly improved. Substantial efforts should be made to develop improved models and data for use on a case-by-case basis to improve decisionmaking on emissions control strategy alternatives. There is also a need to investigate the distribution of costs and benefits among different individuals within society, and the effects of emissions controls and pricing policy on this distribution. (See Chapter 13.)

## NATIONAL PRIMARY AND SECONDARY AMBIENT AIR QUALITY STANDARDS

Pollutant and type of standard	Averaging time	Frequency parameter	Concentration	
			$\mu\text{g}/\text{m}^3$	Parts per million
Carbon monoxide: Primary and secondary.....	1 hr.....	Annual maximum <sup>1</sup> .....	40,000	35
	8 hr.....	do.....	10,000	9
Hydrocarbons (nonmethane): Primary and secondary	3 hr (6 to 9 a.m.).....	do.....	<sup>2</sup> 160	<sup>2</sup> .24
Nitrogen dioxide: Primary and secondary.....	1 yr.....	Arithmetic mean.....	100	.05
Photochemical oxidants: Primary and secondary.....	1 hr.....	Annual maximum.....	160	.08
Particulate matter:				
Primary.....	24 hr.....	do.....	260	-----
Secondary.....	24 hr.....	Annual geometric mean.....	75	-----
	24 hr.....	Annual maximum.....	150	-----
	24 hr.....	Annual geometric mean.....	<sup>3</sup> 60	-----
Sulfur dioxide:				
Primary.....	24 hr.....	Annual maximum.....	365	.14
	1 yr.....	Arithmetic mean.....	80	.03
Secondary.....	3 hr.....	Annual maximum.....	1,300	.5

<sup>1</sup> Not to be exceeded more than once per year.

<sup>2</sup> As a guide in devising implementation plans for achieving oxidant standards.

<sup>3</sup> As a guide to be used in assessing implementation plans for achieving the annual maximum 24-hr standard.

Source: EPA Regulations 40 CFR 50; and Commerce Clearing House, Inc., "Pollution Control Guide," 1974.



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## APPENDIX B

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EXECUTIVE SUMMARY FROM "POSITION PAPER ON REGULATION OF  
ATMOSPHERIC SULFATE," U.S. ENVIRONMENTAL PROTECTION AGENCY,  
EPA-4501-75-007, RESEARCH TRIANGLE PARK, NORTH CAROLINA,  
SEPTEMBER 1975

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The suspected adverse health effects of atmospheric suspended sulfates<sup>1</sup> have been of growing concern to the Environmental Protection Agency (EPA). The sulfate issue is beginning to have a significant influence on EPA policies and programs that affect levels of sulfur oxides emissions: the power plant intermittent emission control policy, the power plant tall stack emissions policy, the energy-related program for conversion of power plants from oil or gas to coal operation, the automotive emissions control program, and general policy regarding the need for additional sulfur oxides regulation. In view of the importance of these current regulatory efforts and the potential need for a general sulfate control program, EPA has conducted an extensive review of currently available information regarding sulfates. Also, the National Academy of Sciences (NAS), at the request of the Senate Public Works Committee, and the EPA Science Advisory Board (SAB), at the request of the EPA Administrator, have recently completed independent studies pertaining to sulfates. This report summarizes current scientific and technical information concerning sulfates, and identifies needs for research and development. The report also discusses the implications of our current knowledge for present and long-term regulatory control of sulfur oxides, and presents and evaluates a policy for sulfates.

### *Health and Welfare Effects*

Health-related research indicates that the transformation products of sulfur dioxide ( $\text{SO}_2$ ) in ambient air, principally sulfates, are more likely than sulfur dioxide alone to be responsible for many of the adverse health effects typically associated with sulfur oxides. Toxicological (animal) studies provide evidence that  $\text{SO}_2$ , in the absence of other pollutants such as ozone or particulates, is a mild respiratory irritant, while certain specific sulfate compounds, especially sub-micronized sulfuric acid aerosol, are more severe respiratory irritants. Epidemiological studies<sup>2</sup> conducted in several U.S. cities suggest that high daily or annual sulfate levels are associated with increased attack frequency in asthmatics, worsened symptoms in cardiopulmonary patients, decreased ventilatory function in school children, and symptoms of acute and chronic respiratory diseases in children and adults. The association of these health indicators with sulfates was stronger than that for  $\text{SO}_2$ . Accurate quantification of effects levels<sup>3</sup> must await future research. When viewed together, the results of the toxicological and epidemiological studies suggest that specific sulfate compounds may also be responsible for the observed

<sup>1</sup> "Sulfates," as used in this report, is defined by the measurement method used in health studies and the National Air Surveillance Network, i.e., material collected on a high-volume sampler filter and analyzed as water soluble sulfates. These can include acid-sulfate (e.g., sulfuric acid, ammonium bisulfate), neutral metallic sulfates, adsorbed  $\text{SO}_2$ , and sulfites.

<sup>2</sup> Principally conducted through the EPA Community Health and Environmental Surveillance System program (CHESS).

<sup>3</sup> Best judgment sulfate levels tentatively associated with adverse health effects in the preliminary epidemiological studies were as low as 6 to 10  $\mu\text{g}/\text{m}^3$  (24 hour average) and 10 to 15  $\mu\text{g}/\text{m}^3$  (annual) average.



excess mortality associated with high  $\text{SO}_2$  concentrations. However, an association between sulfates and mortality has not yet been tested by field studies.

Considerable research is necessary before the complex relationship between sulfates and health effects can be well understood. The health effects associated with given sulfate levels can be expected to vary with the chemical form and physical size of sulfates, the presence of other pollutants, temperature, and other environmental factors. As both the NAS and SAB reports state, due to the inadequacy of present monitoring capabilities and the current incomplete understanding of the influence of other variables on the sulfates/health relationship, the preliminary sulfate health effects studies should only be considered as indicative of the potential health impact of sulfates. Until more specific information regarding the sulfates/health effects relationship is available, EPA considers total sulfate measurements to be an imperfect but useful indicator of the presence of the toxic sulfate components. Although cautioning that such measurements will contain varying proportions of toxic and relatively non-toxic sulfate compounds, the NAS reports appears to support the EPA position. However, the SAB considers measurements of water soluble sulfate alone to be unreliable indicators of the presence of toxic components in what they term the "sulphur oxides/particulate complex," and, instead, would view high concentrations of total suspended particulate, and/or  $\text{SO}_2$  as better indicators of areas for concern with respect to the health impact of acid sulfates and other toxic sulfate components. These divergent opinions can be resolved only by further monitoring and health effects research.

Economic welfare effects associated with sulfates are ecological and agricultural damage, materials damage, and visibility degradation. Sulfates appear to be a major factor in producing acid rain in a large portion of the Eastern U.S. Research into the significance of these effects is limited and, for the most part, such effects cannot now be quantitatively related to levels of sulfates in the air.

#### *Emission and Concentration Distribution*

Emissions of sulfur compounds, both natural and manmade, are the principal source of atmospheric sulfates. Although manmade  $\text{SO}_2$  emissions represent only half of the total sulfur emissions in the Northern Hemisphere, these manmade emissions are concentrated in the relatively small industrialized areas where they far outweigh natural production. Power plant emissions, which currently account for about 55% of manmade  $\text{SO}_2$  emissions in the U.S., have been a rapidly growing component of the  $\text{SO}_2$  emission complex. While total manmade emissions increased by 45% between 1960 and 1970, power plant emissions increased by 90%.

Currently, about 1% of sulfur oxides emissions come from automobiles, emitted predominantly as  $\text{SO}_2$ . Although the contribution to total sulfur oxides loading is not likely to change, emissions from new cars equipped with the catalytic converter are partially in the form of highly toxic submicron sulfuric acid aerosol. Since automotive emissions do not contribute significantly to current sulfate levels and originate from mobile sources, control strategies differ from those for stationary sources. The automotive sulfuric acid issue is not considered in this discussion of the more general sulfate problem.

Based on National Air Surveillance Network data, a large portion of the eastern United States has recorded sulfate concentrations significantly higher than concentrations generally observed in other sections of the country. Urban levels range from 10 to 24 micrograms per cubic meter ( $\mu\text{g}/\text{m}^3$ ) and nonurban levels range from 8 to 14  $\mu\text{g}/\text{m}^3$  (annual average) in a 24-state region east of the Mississippi, roughly bounded by Illinois and Massachusetts to the north and Tennessee and North Carolina to the south. In this 24-state region, the 1972 average of nonurban concentrations exceeded 10  $\mu\text{g}/\text{m}^3$  (annual average) with an urban concentration average of about 13.6  $\mu\text{g}/\text{m}^3$ . The high sulfate levels in the 24-state area appear to be spatially correlated with high  $\text{SO}_2$  emission density, high rainfall acidity patterns, and a high density of power plant locations. The remainder of the country does not exhibit similar sulfate concentrations on a regional scale. The 1972 urban average outside the 24-state northeastern region was 7.9  $\mu\text{g}/\text{m}^3$ ; whereas, the nonurban annual average was 4.4  $\mu\text{g}/\text{m}^3$ . There are some areas, however, such as the Southern California Coastal Basin, in which high sulfate levels are observed. The 11 stations in this area measured an annual average sulfate concentration of 11.1  $\mu\text{g}/\text{m}^3$ . Similarly, Tampa, Florida, recorded an annual sulfate level of 11.9  $\mu\text{g}/\text{m}^3$  in 1972, although nonurban stations in this region averaged 4.9  $\mu\text{g}/\text{m}^3$  for the same period. Thus, while these areas do not exhibit the regional concentration problems characteristic to the northeastern U.S., they do have high local sulfate concentrations.

#### *Atmospheric Chemistry and Transport*

Sulfur dioxide is oxidized to sulfuric acid and other sulfates by several mechanisms, most involving reactive agents such as photochemical smog, ammonia, catalytic metals, and fine particulates. Temperature and humidity also influence the reaction. These agents can complicate the relationship between  $\text{SO}_2$  and sulfates; for example, reductions or increases in  $\text{SO}_2$  concentrations may not result in proportional reductions or increases in sulfate levels because of the presence of other agents that affect the formation reaction. Inadequate knowledge concerning formation mechanisms currently precludes quantitative assessment of catalytic agent influences.

Studies of large point sources before and after unit start up indicate measurable increases in sulfate concentrations as far as 40 miles away. Investigations of sulfate formation in plumes of coal-fired plants with particulate control indicate that the oxidation rate of  $\text{SO}_2$  is negligible for the first 10 to 20 miles but increases to 3%/hr or more thereafter. Similar studies of an oil-fired plant tentatively indicate that the oxidation rate may be more rapid in the first 10 miles (10 to 20%/hr), with the rate then becoming comparable to that of a coal-fired plant plume. This potentially rapid initial oxidation rate in the oil fired plant plume may be the result of certain components in the emitted flyash that catalyze the reaction.

Since sulfates formed in plumes are very small particles, the removal rate for sulfates by ground surfaces is much slower than the removal rate for  $\text{SO}_2$ . Once formed, these sulfate particles may be transported for hundreds of miles, although their downwind concentration is diminished by dispersion. In addition, tall smokestacks provide a long air-borne residence time for  $\text{SO}_2$  before ground removal takes place



and thus may permit substantial sulfate formation and transport to occur. In this respect,  $\text{SO}_2$  emissions from tall stacks theoretically may result in greater sulfate formation than equivalent emissions from lower level sources. This conclusion is supported by limited experimental observations in St. Louis. However, tall stacks will also provide for increased dilution of the sulfates through wider dispersion. The impact of such emissions on sulfate levels in downwind areas has not been determined and is subject to debate. The SAB suggests that because of dispersion, the major impact would occur relatively near the emission source, but an NAS estimation technique suggests non-negligible impacts at distances of 300 miles.

Although urban  $\text{SO}_2$  levels decreased by about 50% between 1960 and 1970, no consistent similar trend has been observed for urban sulfates. Long-range transport and complex precursor relationships have been hypothesized as explanations of this phenomenon. While  $\text{SO}_2$  emission reductions in cities (with a consequent decrease in ambient concentrations of  $\text{SO}_2$ ) likely resulted in less locally formed sulfates, increases in nonurban  $\text{SO}_2$  emissions (primarily from power plants) may have caused regional sulfate increases that, on balance, offset the local decreases. This explanation is supported by the apparent increase in manmade sulfates at a limited number of eastern nonurban sites for which data are available. This increase roughly parallels the increase in overall  $\text{SO}_2$  emissions during that time. Although, in aggregate, urban sulfate levels showed little change, variable trends were observed for different cities. Variations in both the spatial distribution of sulfur oxides emissions and in atmospheric chemistry could affect the relative magnitude of local versus imported sulfates and account for the variable trends for individual cities.

Both EPA and NAS consider the above stated hypotheses plausible; however, the SAB suggests that the impact of nonurban sources on urban areas is likely to be minor and prefers to explain the observed trends in terms of precursor-limited sulfate formation mechanisms, primary emissions of sulfates, and errors in the measurement methods. The SAB bases their conclusions regarding transport on the assumption that dilution and removal would reduce sulfates to negligible levels during transport and not on the evidence of any transport models or measurements. In the opinion of the SAB, the available evidence does not substantiate the validity of their assumptions or any of the explanations offered. These divergent views underscore the need for additional research.

Despite the uncertainties concerning the relationship between  $\text{SO}_2$  emissions and ambient sulfate concentrations, EPA believes that the available evidence suggests that further increases in  $\text{SO}_2$  emissions are likely to produce increases in regional sulfate levels. Sulfate increases are not likely to be proportional to the total  $\text{SO}_2$  emissions increase because of the spatial distribution of the important sources and the complex formation mechanisms.

### *Control Alternatives*

Although control of catalytic agents such as particulates and oxidants may eventually prove to be an important component of a sulfate control strategy, an examination of current emission trends and pollutant formation information indicates that control of atmos-



pheric sulfates will probably depend primarily on control of  $\text{SO}_2$  emissions. A variety of systems and concepts for  $\text{SO}_2$  control that are applicable through 1990 have been examined to provide better definition of research and development objectives. The primary  $\text{SO}_2$  control technologies for sulfate control and their applicability are discussed:

1. Naturally occurring low sulfur fuels will continue to be important in controlling  $\text{SO}_2$  emissions, but are not likely to provide a total solution to the problem of  $\text{SO}_2$  and sulfates control due to their limited supply, at least in the near-term.

2. Clean fuel allocation and redistribution, fuel switching, intermittent control, and tall stacks may contribute to achieving present  $\text{SO}_2$  standards; however, the regional transport theory suggests that these methods would have minor impact on preventing increases in regional atmospheric sulfate levels.

3. Flue gas desulfurization will probably be the principal large stationary source control technology available for at least the next 10 years. Physical coal desulfurization can also contribute to sulfur oxides control during this same time interval.

4. Advanced fuel pretreatment technologies (liquefaction, gasification) have a significant potential for reducing  $\text{SO}_2$  emissions, especially for small point and area sources, but will probably not have a major impact before 1985.

5. Ultimately, alternate energy supply systems (solar energy, thermonuclear fusion), improved combustion technologies (fluidized bed combustion), and general improvements in energy utilization efficiency should provide more effective use of energy resources with less environmental degradation.

#### *Information Gaps and Research Needs for Sulfate Regulation*

As evidenced by the previous discussion of health effects and transport mechanisms, considerable uncertainty exists in interpreting the limited scientific data base on sulfates. Both the SAB and the NAS place a high priority on the initiation of comprehensive research programs that are needed before major control strategy decisions can be made.

An EPA analysis of major research needs indicates that development of the data and information necessary for a sulfate regulatory program would require 3 to 5 years. In this regard, if EPA were to set a National Ambient Air Quality Standard (NAAQS) for sulfates, it could not realistically be proposed before 1980 or 1981. Important research needs are summarized below:

#### *Monitoring*

A critical path in the research effort is the need to develop advanced monitoring methods. Important components of the epidemiological, toxicological, and atmospheric formation studies depend on the characterization of sulfates by such monitoring methods. The development of these techniques is expected to take 1 to 3 years, thus extending the completion of some aspects of all research areas.

#### *Health and Welfare Effects*

Appropriate dose-response curves should be developed. The chemical composition and physical characteristics of the harmful sulfur com-

pounds should be identified. The program to accomplish this will include toxicological work, clinical studies of human response to specific sulfates, and continued epidemiologic studies. Sulfuric acid and other specific sulfate monitors are needed for more precise quantification of exposures. Dose-response functions are needed to assess the effects of atmospheric sulfates on ecological systems and structural materials. These effects include economic losses to materials and crops caused by sulfates and/or acid rain.

#### *Physical/Chemical Transformation and Transport*

The oxidation rates of  $\text{SO}_2$  to sulfate in ambient air as well as in power plant and ground-level urban plumes must be determined. The role of precursors and catalysts in sulfate formation should be further assessed. Models must be developed to estimate both local concentrations and long-range transport phenomena for sulfates. Research in this area is critical to the development of control strategies.

#### *Improved Control Technologies for Sulfur Dioxide and Sulfates*

If stringent control of large  $\text{SO}_2$  point sources is required as part of a sulfate control strategy, current  $\text{SO}_2$  scrubbing technologies may not have adequate removal efficiencies. Demonstration projects designed to achieve greater than 90% removal efficiency, particularly for new sources, will be evaluated. Also, further development of alternative combustion technologies, such as fluidized bed systems, is needed.

#### *Potential Regulatory Strategies*

Although the information required to determine and support a control program for sulfates may not be available for several years, a preliminary analysis of regulatory options has been made to aid planning and to help focus research and development programs.

Regulatory approaches currently available under the Clean Air Act (CAA) were examined to assess their potential utility in a sulfate control program. Options such as hazardous standards (CAA Section 112), emergency powers (CAA Section 303), and abatement conferences (CAA Section 115) do not appear appropriate as primary approaches for regulating sulfates because of their inherently limited scope.

Sulfates exhibit those characteristics<sup>4</sup> identified in the Clean Air Act for pollutants to be controlled through National Ambient Air Quality Standards (NAAQS). Despite the legal rationale for this approach, potential implementation problems exist. NAAQS implementation generally has required the use of a pollutant emissions/ambient air quality relationship to develop emission regulations that apply within currently established Air Quality Control Regions. Due to the complex sulfate formation mechanisms and the apparent transport through multistate regions, such a relationship may be impossible to develop. Another problem with the NAAQS approach would be the definition of a sulfate "threshold" level below which sulfate-associated health effects are insignificant.

Although New Source Performance Standards (NSPS) can be a valuable tool for ensuring minimal emissions of  $\text{SO}_2$  from new major

<sup>4</sup> The pollutant must have "an adverse effect on health and welfare" and result from "numerous or diverse" sources.



sources, this approach may not provide adequate control to deal fully with the sulfate problem.

Since long-term implementation difficulties are possible with an NAAQS and resulting state implementation plans, alternative regulatory options must be explored over the next several years. These options include regional emission limitations for  $\text{SO}_2$ , increased control of sulfate precursors, and economic incentives.

### *Policy Implications*

In view of the available data, it is the judgment of EPA that an air quality standard or other major regulatory program for sulfates is not supportable at this time. Additional research is needed in order to fill the information gaps described earlier. The EPA research effort will focus on improving monitoring capability to permit identification of particle size and chemical form of toxic sulfates, developing more comprehensive health effects data, and characterizing the long range transport and transformation mechanisms. This research program will require several years to complete; consequently, it is doubtful that a comprehensive regulatory program specifically for sulfates could be initiated before the end of the decade.

Nevertheless, until further research makes a comprehensive regulatory program possible, EPA must respond to the potential sulfate problem suggested by the preliminary sulfate/health effects information cited earlier. Although considerable uncertainty exists concerning the relationship between measured ambient sulfate concentrations and adverse health effects, the preliminary health effects information can be useful in identifying areas of potential health concern.

As described previously, a large portion of the northeastern United States is experiencing relatively high annual sulfate concentrations. Nonurban concentrations have averaged in excess of  $9 \mu\text{g}/\text{m}^3$  throughout this 24-state region. The average of urban concentrations has been about  $13 \mu\text{g}/\text{m}^3$  (annual average). As mentioned earlier, this area of high sulfate concentrations correlates spatially with high  $\text{SO}_2$  emission density, high rainfall acidity patterns, and a high density of power plant locations. Furthermore, the region exhibits widespread violation of the national primary ambient air quality standard for suspended particulate matter, a potential precursor agent in the formation of sulfates. High sulfate concentrations have also been observed in several isolated urban areas through the remainder of the country.

Given the significant potential for sulfate-related health risk due to the multiple influence of high sulfate concentrations, high precursor concentrations, and high  $\text{SO}_2$  emission density, prudence dictates that EPA adopt a policy of avoiding aggravation of existing conditions by minimizing further increases in the relatively high sulfate levels in the northeastern United States and other more localized problem areas. In addition, close attention must be paid to sulfate trends in areas of lower sulfate concentrations. Although this goal of avoiding sulfate increases will primarily be achieved by minimizing  $\text{SO}_2$  emission increases, existing programs for control of pollutants such as oxidants and particulates may provide some measure of sulfate control by limiting sulfate formation processes.

Opinions differ over where, and to what extent,  $\text{SO}_2$  emissions should be limited to adequately address the potential sulfate problem.



There is general agreement that SO<sub>2</sub> emissions increases should be avoided in or near urban areas where ambient concentrations of sulfates, SO<sub>2</sub>, or total suspended particulates are high. The NAS placed high priority on abating SO<sub>2</sub> emissions from sources located in or near urban areas with high concentrations of sulfur dioxide and sulfates. In addition, the NAS is concerned about the effects of area-wide increases in SO<sub>2</sub> emissions on regional sulfate levels. The SAB, however, does not share the same degree of concern for the impact of area-wide SO<sub>2</sub> emissions. Rather, the SAB suggests that increased SO<sub>2</sub> and other sulfate precursor emissions may have primarily a local impact on sulfate formation, and "that increases in exposure to sulfur oxides or particulates in localities where the sulfur dioxide and/or total suspended particulates exceed primary standards should be viewed with grave concern."

EPA considers the points addressed in both reports as important and essentially compatible with the Agency's assessments. Current efforts to attain the primary standards for the criteria pollutants are responsive to the SAB's concerns. In addition, EPA believes that the area-wide concern must be addressed by minimizing increases in SO<sub>2</sub> in the areas of maximum sulfate impact. A strategy of minimizing regional and local increases in SO<sub>2</sub> emissions can be implemented through existing regulatory options such as State Implementation Plans (SIPs) and New Source Performance Standards (NSPS).

A policy of minimizing SO<sub>2</sub> emission increases is generally consistent with other Agency policies previously announced. These policies include the Clean Fuels Policy, the limited application of intermittent control systems (ICS), and the significant risk aspect of oil-to-coal conversions.

The EPA Clean Fuels Policy is intended to make it unnecessary for plants to switch to lower sulfur fuels to comply with state regulations where such compliance is not needed for attainment and maintenance of the national health-related standards for SO<sub>2</sub>. By revising SIPs appropriately, plants currently in areas meeting primary air quality standards could continue to burn currently available fuels; no switch to higher sulfur fuel is intended. Therefore, sulfur emissions from these sources should not increase.

With respect to EPA policy on intermittent control systems (ICS), a limited number of isolated power plants may be permitted to use intermittent emission control to meet air quality standards, temporarily deferring expenditures for costly continuous emission controls. Eligible plants are already burning coal and, under ICS, will continue to burn existing fuel except during adverse meteorological conditions, at which point they will reduce emissions by switching to a lower sulfur fuel or shifting generation load. Again, total sulfur emissions from these sources should not increase and may actually be slightly reduced.

The Energy Supply and Environmental Coordination Act of 1974 (ESECA) provides the Federal Energy Administration with the authority to prohibit a power plant from burning oil or natural gas subject to certification by EPA of the plant's ability to burn coal in compliance with certain environmental requirements. Two requirements relate to a plant's ability to burn coal without contributing to a violation of primary standards for total suspended particulate

or sulfur dioxide. In this regard, if certain legal criteria are satisfied (regional limitation), EPA may specify alternate emission requirements (primary standard conditions) to be met temporarily by converting plants. An additional requirement of ESECA states that conversions cannot result in an increase in the emission of unregulated pollutants or pollutant precursors to levels that may result in a significant risk to public health. Based on currently available health effects information, EPA has decided to apply this "significant risk" provision only with respect to sulfates. Under the significant risk provision, EPA plans to restrict emissions of sulfate precursor pollutants—sulfur dioxide or particulate matter—if a converting plant is located in an area with high sulfate concentrations and with concentrations of particulate or sulfur dioxide in excess of primary standards.

Though currently available information does not now permit the establishment of a comprehensive sulfate regulatory program, the information does suggest a need to minimize increases in regional sulfur oxides emissions as a means of preventing increased levels of atmospheric sulfates. In the interim, prior to the initiation of any comprehensive control program, existing regulatory options can be effective in limiting increases in sulfate concentrations. The "significant risk" policy for converting power plants, the vigorous enforcement of state implementation plans for the control of sulfur dioxide and particulates, and the increasing application of new source performance standards to power generating facilities are vital components of an overall strategy that should limit growth of ambient sulfate levels. EPA analysis indicates that these regulations and policies should prevent major  $\text{SO}_2$  emission increases through 1980 in the regions of maximum sulfate impact. Until information is available to support the enforcement of a more rigorous sulfate regulatory program, the use of these currently applicable regulatory measures should provide reasonable protection against increased health risk from sulfates.





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## APPENDIX C

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MODEL RESEARCH INSTITUTE

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Consider the following model:

The institute would be located on the campus of a university, probably near one of EPA's main laboratories. The institute would be professionally staffed by one, highly qualified scientists from EPA, two, faculty from the university, three, postdoctoral research associates, four, graduate students, and five, visiting scientists.

Highly qualified researchers from EPA laboratories would carry on work in the institute. There would be a projected "flow through" of these scientists, with anticipated tenure of one to five years; though individuals particularly effective for the purposes of the institute may have longer tenure. The university would supply faculty members from the various departments to be members of the institute and to be housed and conduct their research in the institute. EPA personnel in the institute would carry adjoint appointments in the academic departments so that they could supervise postdoctoral research associate and graduate students and could teach some courses associated with their expertise.

Postdoctoral research associates would be brought in by contract with the university and have tenure of 1-3 years before moving on to other universities, industry, or government labs. This would educate a continuing cadre of the nation's young scientists in society's environmental problems, would bring a continuing fresh flow of ideas from qualified young minds as they leave academic departments from all over the nation, and insure a force of bright energetic people to do much of the research of the institute. It would provide these young PhDs with the opportunity for multidisciplinary research.

In much the same spirit as postdoctorals would participate, so also would graduate students be trained in the vital multidisciplinary environmental area. At the same time they would perform a share of the research. (It is reasonable to suppose that a reasonable number of new epidemiologists could be trained in such a program—actually working on EPA related problems.)

A key part of the institute would be the visiting scientists' program. This program would bring senior scientists on Fellowships from around the world into the institute for a period of a year. The fellowships would be set up to be awarded on a competitive basis, and be established as a prestigious award. The fellowships would go, for example, to senior people on sabbatical leave from universities or those on training leave from industry and government. This program would insure a continual flow of ideas and creativity from some of the best minds in these science areas in the world. It would establish first hand familiarity of these people with the problems to be solved in the environment, so that when they returned to their own institutions, their own research would reflect a modified direction.

A research institute of this nature would significantly multiply EPA's effective research base in the outside world. It would significantly multiply the intellectual base being used for the solution of EPA's research problems.





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APPENDIX D

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HEALTH EFFECTS OF  
FOSSIL FUEL COMBUSTION PRODUCTS

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REPORT OF A WORKSHOP SPONSORED BY THE CORNELL ENERGY  
PROJECT AND ELECTRIC POWER RESEARCH INSTITUTE, INDIAN  
WELLS, CALIF., NOVEMBER 11-13, 1974

(Prepared by Dr. Cyril L. Comar, Workshop Coordinator, Electric Power  
Research Institute)

SUMMARY LIST OF RESEARCH PRIORITIES

For the convenience of the reader, a list of proposed studies developed in the Workshop is given below. All are considered to be of very high priority; no attempt was made at priority ranking, either among or within the group areas. This list should be regarded only as an identification of the general area of research. The individual chapters of the report should be consulted for further details.

*Epidemiological Studies*

Determination and quantification of health effects resulting from exposure to low levels of pollutants and to changes of levels of exposure.

Determination of exposure/effects relationships in special risk groups.

Evaluation and surveillance of new, potentially harmful pollutants.

Development of further international comparisons and cooperation.

*Controlled Biological Studies*

Human:

- (a) Tests of airway narrowing.
- (b) Synergistic effects of gas-aerosol mixtures.
- (c) Form in which sulfur oxides are most damaging.
- (d) Observations and dose response for gas-gas interactions.

Animal and in vitro:

- (a) Aerosol parameters likely to influence toxicity or irritancy.
- (b) Effects in disease states.
- (c) Chemical changes in the mucus and effects on mucociliary transport mechanisms.
- (d) Effects on alveolar macrophage function.
- (e) Effects on structural elements of the lung.

Pollutant interactions:

- (a) Effects, in humans and animals, of pollutant mixtures similar to those existing in air and quantitatively and qualitatively identified; role of temperature and humidity in modifying such effects.

*Mutagenesis and Carcinogenesis*

Chromosomal aberrations in populations occupationally exposed to high levels of potential mutagens.

Birth defects and other anomalies among populations exposed to high levels of oxidants (e.g., ozone).

Mechanisms of interactions of potential mutagens and carcinogens with informational macromolecules.

Study of populations occupationally or otherwise exposed to point sources of known or suspected carcinogens.

### *Trace Elements*

Characterization of trace element emissions from fossil fuel plants (see Chapter V).

Determination of concentration, translocation, uptake, and conversions of elements such as lead, arsenic, selenium, and mercury in components of the biosphere.

Study of metabolism and toxicity, in human beings, of selected trace elements such as lead, arsenic, selenium, and nickel.

Evaluation of the role of trace elements in catalysis of atmospheric reactions of gaseous pollutants, especially  $\text{SO}_2$  and  $\text{NO}_2$ .

### *Monitoring and analysis*

Characterization of trace element emissions (as above).

Sampling and analytical methods for selenium, mercury, arsenic, and beryllium.

Better methods for  $\text{NO}_2$ ; monitoring of peroxyacetyl nitrate (PAN).

More definitive methods for particulates, and evaluation of emissions from fly ash dumps and coal piles.

Complete characterization of physical and chemical pathways and factors affecting the sulfur compounds that enter the atmosphere.

Characterization of acid-sulfate aerosols and personal monitoring for the sulfur oxides.

Improved air monitoring for sulfur oxides to permit trend monitoring, compliance, and more reliable retrospective and prospective assessment of health effects.

## REFERENCES AND FOOTNOTES

1. Unless otherwise specified, the term "sulfates" as used in this report is defined by the measurement method used in the preliminary health studies and the National Air Surveillance Network. The method measures the material that is collected on glass fiber filters of high-volume samplers and analyzed as water-soluble sulfate. This can include sulfuric acid, soluble sulfate salts, adsorbed sulfur dioxide, sulfite salts, and sulfates formed due to sampling and analytical artifacts.
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